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20602

THE UNIVERSITY OF ROCHESTER

ROCHESTER, NEW YORK

CONTENTS

1. SUMMARY

The development and testing of ultraviolet sources and detectors for radiation at low levels of intensity have been continued during the interval covered by this report. Experiments have been carried out on various methods for coating aluminum mirrors for high reflectivity and low scattering in the ultraviolet. Tests have been made on several types of refrigerating equipment to permit operating a microtome at controlled low temperatures for cutting sections of frozen tissue thin enough to meet the requirements of miscrospectroscopy.

II. PROGRESS FROM JANUARY 1, 1953 to JUNE 30, 1953

1. ORGANIZATION OF THE PROJECT

The project continues to be organized jointly under the Department of Medicine of the School of Medicine and Dentistry and under the Institute of Optics. During the period covered by this report, approximately half of the cost of operation was covered by the Office of Naval Research. The other half was covered by the U.S. Public Health Service. On the basis of present arrangements, the support by ONR will continue to September 30, 1955 and by the U.S. Public Health Service to September 30, 1954. The ability to plan on a relatively long range basis is extremely helpful.

A grant of $4655 has been made by the Research Corporation to cover the cost of equipment for pulse counters to be used in measuring radiation at extremely low levels of intensity.

2. LABORATORY AND SHOP FACILITIES

Space on the second floor of Wing R of the Medical Center of the University of Rochester is being used as previously. This space, which amounts to about 1600 square feet, including the small instrument shop, is being made available by the Department of Psychiatry. Additional space will be needed in the near future if work is to be carried out on both physical and biological problems in this field.

The Institute of Optics is continuing to make available the facilities of its instrument shop at the River Campus, for the use of a full-time instrument maker employed under this project. The optical shop has also been available for the construction of special optical equipment.

The need for a good milling machine continues as before (preferably a No. 12 Van Norman). If such a mill can be obtained, either on loan from ONR or by purchase, most of the instrument work that is now being carried out in the shop at the Institute of Optics can be done in the new shop close to the laboratory. This arrangement would have marked advantages from the point of view of efficiency.

3. EQUIPMENT

a. Sources of Ultraviolet Radiation:

The D.C. power supply for the Nester lamp, which was described in previous reports, has been built into final shape for routine use. The circuit is shown in Fig. 1. Automatic switching is employed, so that the operator must merely close the main switch in order to start the lamp. One relay switches on the high voltage after 60 seconds and another relay switches off the Nester lamp filement 30 seconds later. Pilot lights give a check on correct operation.

A Westinghouse Hypersil transformer is employed, with the following specifications: Primary - 115 V, 60 Cycles, 3/4 KVA; two secondaries, each 241 V, 1.56 A. Four 866A Mercury Vapor Rectifiers are used, with a rated peak current of 1.0 amps., average current of 0.25 amp., and a voltage drop of 15 V. Using full-wave rectification with choke input filter, the ratio of average current per plate to total load current is 0.5, so that the use of two 866A tubes in parallel is indicated. The peak current is within the rating, being four times the average current. Two U.T.C. S37 (20 H @ 550 mA) chokes were used in parallel, giving 10 H @ 1.1 amp. with a resistance of 30 ohms. The lamp current is controlled by means of a 150 ohm Ohmite variable resistor and a fine control 15-ohm Ohmite variable resistor. A Sola transformer (500 VA) is used to stabilize the A.C. supply to the circuit.

Tests were made of the stability of the Nester lamp, when connected to this D.C. power supply. It was felt that it would be undesirable to employ a photomultiplier, D.C. amplifier and Brown recorder, unless the stability of each of these units had been determined, at least to 0.1% rms noise. Accordingly, a vacuum photocell (RCA 934), operated from a 90 V dry battery, was used with a Rawson meter having 2.0 μA full scale (1 division = 0.02 μA) for indication. The A.C. supply circuit is shown in Fig. 2.

The average fluctuations in photomultiplier current do not exceed 0.01% over a 15-minute interval. By contrast, when the lamp is supplied with A.C. regulated by a Sola transformer, the fluctuations are usually more than 0.1%, and frequently exceed 1%.

It will of course be desirable to measure the stability of the lamp within limited wavelength bands in the ultraviolet, but it seems likely that a lamp of this type can be used without monitoring, for accurate spectral absorption measurements in the ultraviolet.

The development of the high intensity hydrogen lamp has been completed at M.I.T. by Dr. Harold Wyckoff. One of these lamps will be delivered in the near future. Xenon lamps have been ordered from Siemens Electric Lamps and Supplies, Ltd. and from British Thomson-Houston in England. A motor-generator with a capacity of 125 V and 120 A D.C. has been transferred by ONR to serve as a supply for discharge lamps which require heavy D.C. current.

b. Monochromators

The wave-length drum of the Leiss double monochromator has been calibrated in the ultraviolet, using mercury lines. Several optical systems have been compared for making reliable reflectivity measurements.

c. Microscopes

Dr. Burch of Bristol University informed us in May that work was in progress at that time on the aspherical mirrors for our microscope of his design. It is our understanding that the mechanical parts are essentially completed. This makes it seem likely that the instrument will be delivered before the end of 1953.

d. Radiation Detectors

Three E.M.I. photomultipliers (11, 12 and 13 stages respectively) with quartz windows have been received. One Schaetti 17-stage photomultiplier with glass window and Li-Sb cathode has been received. Three similar Schaetti tubes with quartz windows are being constructed.

Several designs are being studied for cooling photomultipliers to temperatures ranging down to -190°C, so as to permit measurements of dark current as a function of temperature. Considerable difficulty is encountered when attempts are made to hold the temperature low in the presence of conduction through electrical leads, if the tube is mounted in a vacuum so as to reduce liquid nitrogen consumption. It seems best, at least for the present, to immerse the tube in air which will greatly increase heat transfer.

e. Spectral Emission of Sources and Spectral Sensitivity of Receivers

It is extremely desirable to know the absolute emission on a spectral basis of the various sources that are likely to be useful in microspectroscopy. These include the Nester hydrogen lamp, the Allen-Finkelstein-Wyckoff high intensity hydrogen lamp, the H-6 high pressure mercury lamp, and xenon lamps of various designs. It is almost desirable to know the sensitivity of the various radiation detectors that are being used on an absolute spectral basis. These include photomultipliers from various laboratories, lead sulphide cells and thermocouples. Such data will make it possible to calculate expected performance for various microscope systems, flux levels and time constants.

Equipment has been designed and is now under construction to make possible such comparisons of sources and detectors. The sources will be compared with a ribbon filament tungsten lamp calibrated at the General Electric Company, running as far as possible into the ultraviolet. The detectors will be compared with an Eppley thermopile, which will be calibrated against a carbon filament lamp that has in turn been calibrated at the National Bureau of Standards. A model 83 Perkin-Elmer monochromator has been modified for this program, by providing for refocusing the exit slit on each of the detectors with a mirror system which is achromatic. The sources will be imaged on the entrance slit by means of two off-axis mirrors, in such a way that radiation can be attenuated by introducing diaphragms into the parallel beam between the two mirrors. This will make it possible to operate over wide wavelength ranges, where both the flux of radiation and the sensitivity of some of the detectors varies widely. Each detector can be adjusted in three coordinates so as to center the most sensitive region on the image of the exit slit by seeking the position where the signal is a maximum. A 60 cps chopper is provided at the entrance slit for the lead sulphide cell, and an A.C. amplifier is under construction. This incorporates a mechanical (Brown) rectifier, so that a D.C. signal can be fed to a Brown recorder. The output from the photomultiplier will be fed to the present D.C. amplifier (Kron) and sent to the Brown recorder

f. Dual Output Laboratory Regulated Power Supply

- 500 to 1500 Volts
- 150 Volts
+100 to 300 Volts

The gain of a 1P21 photomultiplier varies approximately 7% for 1% variation in the overall voltage supplied to the divider. For the photomultipliers made by Dr. N. Schaetti in Zurich, this variation is approximately 17%. Accordingly, if 0.1% precision is required in measurements insofar as this particular factor is concerned, it will be necessary to hold the voltage supplied to a photomultiplier to about 0.01%.

A dual output power supply has been designed and constructed to fill the need for voltages in the 100 - 300 V range and also the need for supplying up to 1500 volts for the divider to be used with photomultipliers. Currents up to 150 mA are ordinarily required for the first application, and up to 2 mA for the second application.

In order to make it possible to reset the voltage applied to a photomultiplier within 1%, an outlet is provided where it is possible to measure a fraction of the total voltage with a type K potentiometer, making it easy to read voltage to better than 0.1%.

The circuit (Figs. 3 and 4) uses a 5U4G rectifier in the low voltage supply, with a pair of 6Y6G pentode tubes as voltage regulator tubes. The negative supply is obtained from the same transformer, using selenium rectifiers, and OD3 and OC3 tubes as voltage stabilizers. Voltages of -300, -210, -150 and -105 volts are available, as well as positive voltages in the range from 100 to 300 volts. The high voltage supply uses a 2X2 rectifier with a 3C24 triode as a voltage regulator. Switches provide for switching the filaments on first, then the low voltage, finally the high voltage, with separate fuses and pilot lamps for each switch.

Table I shows the relation between current and output voltage for the low voltage (300 V) supply at various voltage ranges. Table II shows the percentage ripple and Table III shows the line voltage regulation.

Table IV shows the noise for the high voltage supply (500 to 1500 V). The noise is less than 0.1% for all voltage ranges.

Table V shows the results of tests of stability of the high voltage supply. The voltage was measured with a Type K potentiometer and sensitive galvanometer. No constant voltage transformer was used. Readings were made at 15-minute intervals, over periods ranging from 2 to 8 hours. The mean voltage is given in the second column. The third column shows the average voltage difference between the beginning and end of each 15-minute interval. The corresponding percentage variations are shown in the fourth column. The fifth and sixth columns show the maximum deviation from the mean voltage during the entire run. The data suggest that this circuit can be depended upon to give steady voltage within 0.1% during a 15-minute interval. In view of the fact that photomultiplier output magnifies any fluctuations in the voltage applied to the dynode by 7 for the RCA, it would be desirable eventually to have a source of voltage with even better performance. Some improvement may result if a voltage regulating transformer is used in the A.C. line.

g. <u>1,500 to 5,000 Volt Power Supply</u>

In order to provide voltages up to 2000 V for E.M.I. photomultipliers, and up to 4500 V for Schaetti photomultipliers, a regulated power supply was designed and constructed to cover the range 1,500 to 5,000 V (Figs. 5 and 6).

The output from a full wave rectifier (using two RK72 rectifier tubes) is filtered by a 450 H choke and two 0.5 mfd condensers and the positive side is taken to ground through a

TABLE I

LOW VOLTAGE SUPPLY

Output Voltage vs. Current

Current mA	Voltage Range 100 V	200 V	300 V
0	100	200	300
10	100	200	300
20	100	200	299
40	100	200	299
60	100	199	298
80	99	198	298
100	99	198	297
120	99	198	297
140	99	198	297
150	98	198	296

TABLE II

LOW VOLTAGE SUPPLY

Percentage Ripple (Peak-to-Peak)

Current mA	Voltage Range 100	200	300
0	0.005%	0.0025%	0.0017%
50	0.005	0.0025	0.0017
100	0.005	0.0025	0.0023
150	0.010	0.0050	0.0070

TABLE III

LOW VOLTAGE SUPPLY

Line Voltage Regulation

Line Volts	Voltage Range 100	200	300
80	96		
85	98	187	
90	100	198	
100	100	200	283
110	100	200	294
120	100	200	295
130	100	200	295

TABLE IV

HIGH VOLTAGE SUPPLY

Noise (read on oscilloscope, 1 megohm load)

Range	Output Voltage	Peak to Peak Noise	Voltage Across C4
1	450 - 700	0.05 - 0.03 V	920 V
2	650 - 1000	0.06 - 0.04	1290
3	850 - 1250	0.06 - 0.04	1620
4	950 - 1350	0.42 - 0.96	1840

TABLE V

HIGH VOLTAGE SUPPLY

Stability Tests

Range	Mean Volts	Average Variation (15 minute intervals) Volts	Percentage	Maximum Deviation Volts	Percentage
1 low	539.8	0.10	0.019%	2.35	0.44%
1 middle	635.37	0.49	0.077	0.25	0.04
1 high	816.63	0.56	0.068	6.57	0.08
2 low	758.70	0.14	0.018	2.35	0.31
2 middle	887.08	0.55	0.062	1.74	0.20
3 low	948.35	0.56	0.059	2.39	0.25
3 middle	1142.61	0.35	0.031	3.83	0.34
4 middle	1376.71	3.15	0.229	12.73	0.93

TABLE VI

HIGH VOLTAGE SUPPLY

Output Voltage vs. Line Voltage

Line Voltage	Output Voltage	Variation from Output at 115V	Percentage Variation
90	819.17	+ 0.15	+ 0.018
95	818.68	- 0.34	- 0.042
100	818.49	- 0.53	- 0.064
105	818.87	- 0.15	- 0.018
110	818.94	- 0.08	- 0.010
115	819.02	0.00	0.000
120	819.13	+ 0.11	+ 0.013
125	819.15	+ 0.13	+ 0.015
130	818.86	- 0.16	- 0.020

2C53 triode, acting as a regulator tube. The grid voltage of this tube is controlled by a second 2C53, which acts as a difference amplifier, the cathode potential being derived from a pair of 5651 gaseous voltage regulator tubes, and the grid voltage taken from a tap on a resistor chain across the output voltage.

Since the full wave rectifier is capable of supplying 35 mA, the output current limitation is imposed by the 2C53 tube which is rated at 5 mA maximum. The current requirements of the resistor chain R3, R4, and R5 run from 0.15 mA at 5Kv and the current through the voltmeter is the same, so there is available at the output between 4 and 4.7 mA. This is ample for any photomultiplier requirements, since photomultiplier divider resistor networks normally used, require only 1 mA.

The power supply was constructed on a standard 19" relay rack panel and chassis. The panel is 19" x 13" and the total depth is 1-1/2". A Sola constant voltage transformer is mounted separately.

Tests of stability were made with the Type K potentiometer, as in the case of the low voltage circuit,except the regulating transformer was used. The results are shown in Tables VII and VIII.

h. A.C. Balancing Photometer

Unless a source of radiation stable to about 0.1% can be provided for all regions of the spectrum, and unless an amplifier with approximately equal stability, even at low levels of flux, can be be devised, it will be necessary to monitor the source, so as to produce a spectral absorption curve free from any effects of variation in the source. This can be done by employing two photomultipliers and two D.C. amplifiers, the output of the signal amplifier being fed to a Brown recorder in the usual way and the output of the monitoring amplifier being fed to the slide wire of the Brown recorder. This has been done successfully by Hiltner and Code (J.O.S.A. 40, 149, 1950). The use of two photomultipliers involves some inequality in spectral

TABLE VII

HIGH VOLTAGE SUPPLY

Stability Tests

Range	Mean Volts	Average Variation (15 minute intervals) Volts	Average Variation (15 minute intervals) Percentage	Maximum Deviation Volts	Maximum Deviation Percentage
1	1077.40	1.58	0.15%	7.13	0.66%
2	1325.13	0.15	0.01	0.73	0.06
3	1698.66	0.18	0.01	0.38	0.02
4	2363.18	0.16	0.007	0.38	0.02
5	3868.27	2.32	0.06	8.50	0.22

TABLE VIII

1.5.- 5.0 KV POWER SUPPLY

A.C. Line Voltage Vs. Output Voltage

Voltage	Potentiometer (mV) (Across 1.6 Ohm)	Variation From 115V Value
90	1.1173	- 3.8%
95	1.1241	- 3.5
100	1.1545	- 1.9
105	1.1701	- 1.0
110	1.1764	- 0.7
115	1.1900	0.0
120	1.1904	+ 0.02
125	1.2012	+ 0.5

response in the two beams, and the use of two amplifiers introduces some additional noise.

An A.C. system, in which the two beams are allowed to fall alternately upon the photocathode of a single photomultiplier, is inherently more elegant and appears to have advantages. From the electronic point of view the problem becomes that of distinguishing whether the signal is greater during the odd half of each cycle, and doing something to restore the balance. The balance can be restored by driving an optical wedge or some other device to attenuate the flux in the reference (monitoring) beam. It has appeared to be worth while to develop a sensitive A.C. monitoring system and to compare the threshold of its performance for the same accuracy of indication with that of the best D.C. amplifier that is available.

Several different A.C. systems can be used for this application: (1) A.C. amplification, followed by electronic rectification -- the D.C. signal going to a Brown recorder; (2) A.C. amplification, followed by mechanical rectification (e.g. a Brown converter) -- the D.C. signal going as before to a Brown recorder; (3) A.C. amplification, the signal going to one pair of field coils on a phase-discriminating motor, while the other pair of coils is energized from a reference voltage that is in phase with the chopper. The first of these systems has been explored, and the results to date are summarized in the following paragraphs.

The amplifier design problem called for (a) a high gain, probably narrow band, stable amplifier, (b) a synchronous detector, (c) a D.C. output whose polarity was dependent on the phase of the input (see Fig 7). Four amplifiers have been developed and tested for this system.

Amplifier No. 1

The main amplifier consists of a four-stage (using two twin triodes) amplifier, designed with large degenerative feedback in the unbypassed cathode circuits (see Fig. 8). The gain of such an amplifier (Cruft p. 417) is given as $A = \frac{\mu Z_L}{R_p + Z_L + Z_K(1+\mu)}$

using $Z1 = 30K$, $Rp = 6500$ ohms, $Zk = 10K$. The gain is found to be 2.2 so the overall gain of the amplifier should be $(2.2)^4 = 23.43$.

Decoupling has been placed in all plate circuits to minimize feedback between stages, each decoupling circuit consisting of a small (2K) resistor in series with the load resistor, and an 8 mfd. condenser to ground.

Tuning is accomplished by (a) a parallel-tee filter tuned to 60 cycles in series with the input to reject 60 cycle noise and (b) a parallel tee-filter, tuned to 510 cycles, placed in a feedback circuit between plate and grid of the first tube. This filter being a "reject" filter will feed back a degenerative signal at all frequencies other than 510 cycles, and produce a negligible feedback at that frequency. Thus the amplifier will have negligible gain at all frequencies except 510 cycles. The gain at 510 cycles will <u>not</u> be reduced. (Terman p. 946; Savitzky & Halford RSI, <u>21</u>, 203, 1950; Baird et al J.O.S.A. <u>37</u>, 754, October 1947).

<u>Synchronizing Amplifier</u>.

This circuit provides a synchronizing signal at the grid of one of the multivibrator stages, to insure that the multivibrator will remain in constant frequency and phase relationship with the chopping wheel. The input signal to this amplifier is derived from a lamp and photocell located at the chopping wheel. This a straightforward three stage amplifier, designed solely for maximum gain to provide an output of about 1V when fed from a CE25C phototube. A gain control is provided.

<u>Multivibrator and Synchronous Detector</u>

The Multivibrator (12AU7) is of conventional design (Cruft p. 855-63). The natural frequency is inversely proportional to $R_{mv}\ C_{mf}$, for the circuit used this proportionality constant was found to be 5.76. This constant is a function of the plate resistance of the tube, so the grid resistors were made variable to allow adjustment when changing tubes.

The Blocking Stage (12AU7) is used to couple the square wave output of the multivibrator to the screens of the detector tubes. This is simply an electronic switch, giving "on-off" voltages at the screens of the 6SJ7 detector tubes.

The Synchronous Detector consists of two 6SJ7 tubes, with the output from the main amplifier taken to the grids in parallel. The screen grids are alternately switched on and off, thus one tube is conducting while the other tube is nonconducting. When the multivibrator is in proper phase with the chopping wheel, signals will be developed across the two cathode resistors which will be proportional to the relative amplitudes of the two light beams. Any difference in intensity of the two beams will produce a positive voltage across one cathode resistor - thus a voltage will be fed to the Brown Elektronik potentiometer, the polarity of which will depend on which of the gated amplifier tubes is conducting most strongly (see Fig. 9).

The output of this amplifier is fed to the Brown Elektronik potentiometer which forms part of the overall feedback loop (see Semi-Annual Progress Report No. 4).

Measurements of gain vs. frequency and output vs. frequency were made (see Figs.10 and 11 and amplifier linearity (Figs 12 and 13).

Test runs were made under simulated conditions with reference beam only; with a 2:1 ratio of reference to signal beams; and also balanced beams: (1) with .05 mfd coupling condenser and no filter, (2) with .05 mfd condenser to 510 cps filter, (3) with .05 mfd condenser and 60 cps plus 510 cps filter, (4) with .01 mfd condenser and both filters in. Fig. 14 is typical.

The amplifier and self-balancing photometer was tested by making a series of settings of the manual wedge position and reading the balancing wedge position, as established by the A.C. amplifier. The reading was actually made on the Brown recorder, which is linked to the balancing wedge by means of a pair of G.E. Servo motors (see Semi-Annual Progress Report No. 4, p. 12 and No. 5, p. 8).

The results are tabulated in Table IX. The differences between the wedge settings amount to 1% in some cases, but these differences include whatever errors exist in the photometric calibration of the two Eastman wedges and any slight inaccuracies which may exist in performance of the Servo-motor link between the balancing wedge and Brown recorder, as well as errors due to performance limitations in the A.C. amplifier.

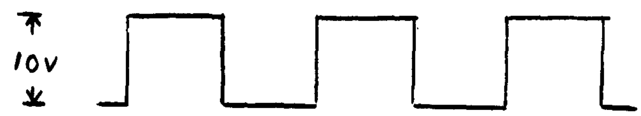
TABLE IX

WEDGE BALANCING TEST WITH AMPLIFIER NO. 1

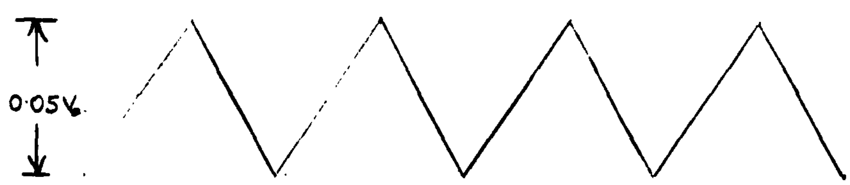
MANUAL WEDGE	PERCENTAGE TRANSMISSION	AVERAGE BROWN CHART READING	PERCENTAGE TRANSMISSION	PERCENTAGE DIFFERENCE
1	40	91.55 ± .05	40	zero
2	33	86.9 " .1	33	zero
3	26	81.9 " .1	26.8	+ 0.8
4	20.9	77.2 " .1	21.3	+ 0.4
5	16.1	72.3 " .1	17.2	+ 1.1
6	13.2	67.9 " .1	14.0	+ 0.8
7	10.2	62.9 " .2	11.2	+ 1.0
8	8.3	58.1 " .1	8.9	+ 0.6
9	6.4	52.2 " .5	6.6	+ 0.2
10	5.2	48.3 " .2	5.6	+ 0.4
11	4.05	42.8 " .6	4.18	+ 0.13
12	3.3	37.8 " .6	3.46	+ 0.16
13	2.55	32.2 " .6	2.73	+ 0.18
14	2.0	27.2 "1.3	2.20	+ 0.20
15	1.6	22.1 " .9	1.75	+ 0.15
16	1.3	15.3 "3.0	1.25	- 0.05
17	1.0	10.1 "4.4	.96	- 0.04
18	.76	5.2 "4.2	.73	- 0.01
19	.64	2.2 "1.8	.62	- 0.02

In considering improvements in the precision and sensitivity, the following were observed:

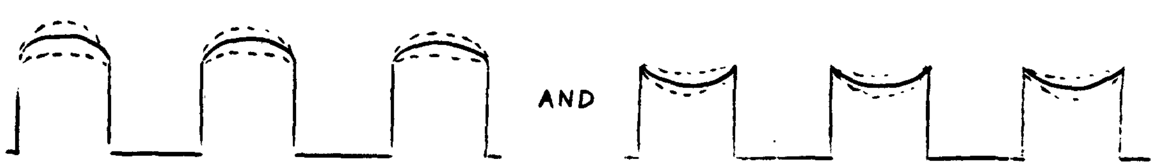
(a) The 6SJ7 gating circuit produces voltage waves at the output terminals of the following shape, for no input signal:



(b) Placing the Brown recorder across the output terminals results in a decrease in amplitude and change in waveshape (caused by large input condenser in the Brown recorder):



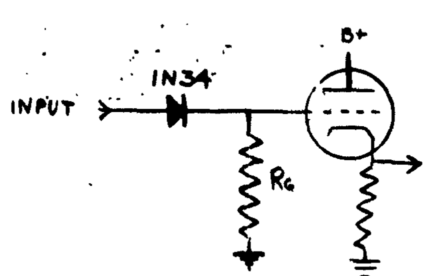
(c) Without the Brown recorder connected, and a signal applied, the wave shapes of the outputs are:



It is to be noted that the signal affects the output of both gating tubes. The net difference between them is a second order effect.

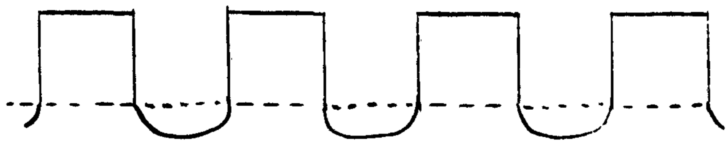
(d) With the Brown recorder connected we can observe little or no change from Case (b).

In order to improve the transfer efficiency, a circuit was added to remove one half of the A.C. wave - allowing only one phase of the output to be affected by the signal:

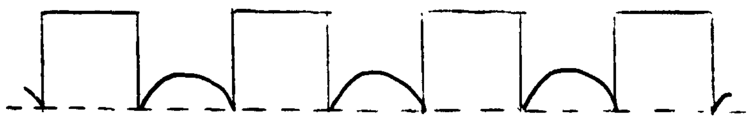


Under these conditions the following phenomena were observed:

(a) With the diode furnishing negative pulses, the tube's conduction was reduced during the gated-off periods:

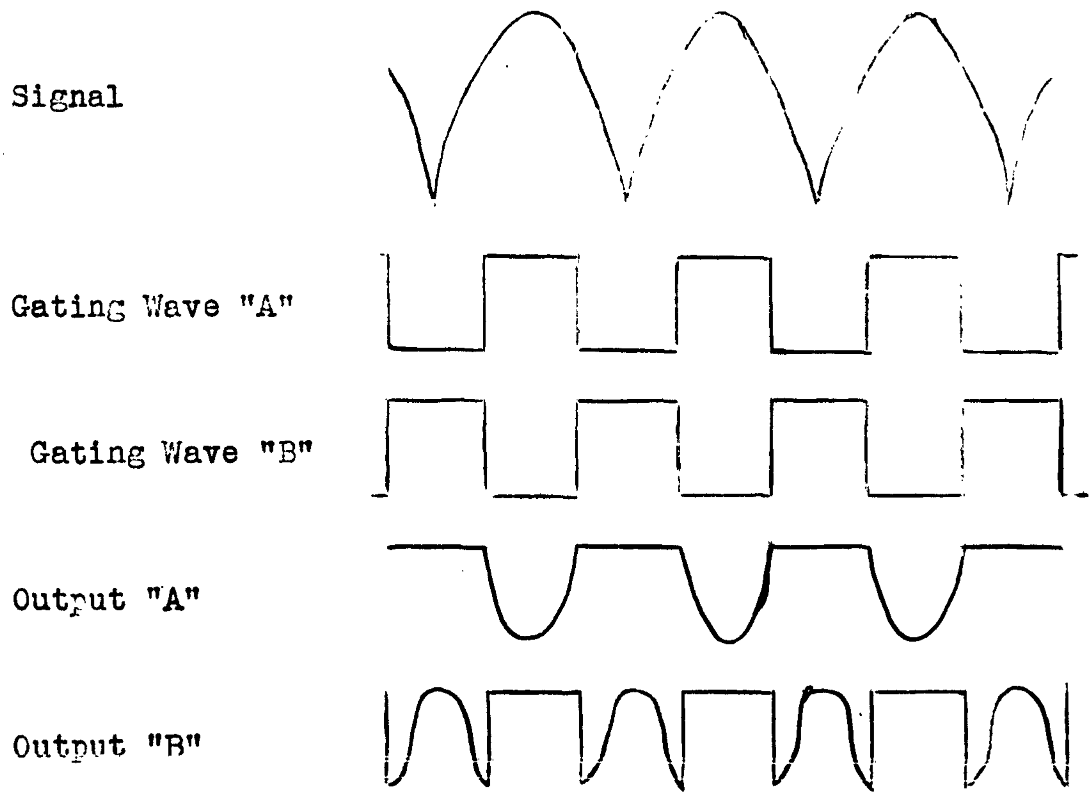


(b) With the diode furnishing positive pulses, the tube's conduction was increased during the gated-off periods:

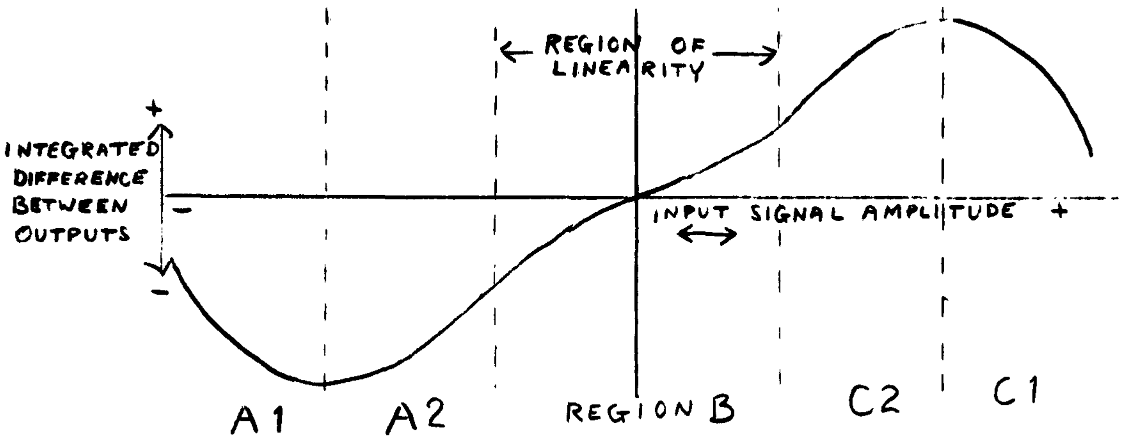


Thus it is seen that the tubes still had appreciable g.p. conductance during the gated-off period. This seems to indicte the inadequacy of this gating circuit.

If the signals applied to this amplifier exceed some small limiting voltage, a wave distortion occurs (due to grid current or cut-off occurring), and this distorted wave, which is applied to the gating tube, gives rise to a signal in <u>both</u> outputs, reducing its sensitivity to a very small order:



This behaviour does not completely nullify the usefulness of the gated amplifier--there is still and integrated signal at the output due to the asymmetry of the two signals, but this effect causes the following behaviour:



If the input signal is undistorted, operation occurs in the central portion "B" and performance is good. However, for large (distorted) signals (regions "A" and "C") performance is poor. If the distortion is excessive, the circuit operates in the portion of the curve (subsections A1 and C1) where the system tends to drive itself further off balance. This behaviour is caused by a saturation in one of the gated amplifier tubes and an approach to saturation in the other by the undesired signal.

Amplifier No. 2

To overcome these limitations, a non-blocking amplifier was built, as well as a gated amplifier, that would not conduct in the gated-off condition. Since the synchronizing pulse is already a square wave, there is no need for the multivibrator, and a straightforward synchronizing amplifier is used (see Fig.15).

This amplifier (Elmore & Sands p193) is a direct-coupled three stage amplifier and feedback from stage 3 to stage 1 is employed for stability. The gain of this amplifier is about 75 (see table). A summary of tests is shown in the following tables and Figs. 16, 17, 18 and 19.

GAIN AND LINEARITY OF NON-BLOCKING AMPLIFIER (see Fig. 16)

Input Volts(510 cycles/sec.)	Output Volts	Gain
0.001	0.075	75
0.003	0.26	86
0.007	0.55	79
0.010	0.70	70
0.030	2.40	80
0.07	5.20	74
0.10	7.30	73
0.25*	14.00	56

*Starts limiting, but is still useable up to 5 volts (No "Spill over" into wrong cycle results)

FREQUENCY RESPONSE AT 100 mV INPUT (see Fig. 17)

Frequency	Output Volts	Frequency	Output Volts
200	1.69	550	4.07
250	2.18	575	4.23
300	2.62	600	4.40
350	3.00	650	4.62
400	3.35	700	4.82
425	3.50	750	5.00
450	3.65	800	5.20
475	3.76	900	5.50
500	3.90	1000	5.70
525	4.00		

The gating circuit uses 6BN6 tubes, which operate very nearly ideally.

Gated off: E_{lim} -5V Resting

E_{quad} -2V Resting

Gated on: E_{lim} +5V

The gating pulses are applied to the limiter grids, the signals are applied to the quadrature grids (0.3 V positive). The linearity of the 6BN6 (quadrature grid) is shown in the following table:

Peak Input to Quadrature Grid Volts	Peak Plate Output Volts
0.5	0.6
1.0	3.0
1.5	6.5
2.0	11.0
2.5	15.5
3.0	18.0
4.0	21.5
5.0	22.5

(See Fig. 19)

A simple difference amplifier followed the gating stage (Fig. 20a). This consisted of a 12AX7 tube, with the outputs from the two 6BN6 gated stages fed to the grids. The 1000-ohm helipot served to balance the two sections of the 12AX7 to give zero voltage difference at the two cathodes for no signal. A signal at either grid now gives rise to a voltage at one cathode, while the other cathode voltage remains constant; thus producing a (pulsating) D.C. voltage across R, the polarity of which is dependent on which grid is most positive.

This simple difference amplifier was found difficult to zero, so changes were made to improve the zero settings (Fig. 20b). R, the output load resistor controls the sensitivity of the system, and was set at 5 ohms, this being the best compromise. A higher resistor gave "hunting" of the recording trace, and lower value gave too "dead" a response.

Table X gives a summary of test runs which were made in a manner similar to those on Amplifier No. 1. Four runs were made, using the output from the chopping system. For the purposes of these tests, an independent calibration of each of the two wedges and its associated part of the optical system (mirror and half reflecting plate) was made. This was done by measuring the D.C. output current of the photomultiplier tube, with an unchopped beam (see Fig. 21).

There is some "hunting" of the Brown recorder, which causes an overall oscillation of a little more than 1% of full scale deflection. Methods of eliminating this are being investigated.

At the dense end of the scale the D.C. signal is 7.5×10^{-10} A. Under these conditions an A.C. signal of 1.0×10^{-10} A, due to a slight unbalancing of the manual wedge, causes a definite response.

Amplifier No. 3

Before the beam splitting and chopping mechanism was set up, it was visualized that Amplifier No. 1 might have much too low gain (22X), so an amplifier was designed to the following specifications:

Unfedback gain	10,000X
Fedback gain	1,000X
Total current drain	Approx. 10 mA
Maximum undistorted output	Approx. 80 V (peak-to-peak)

This amplifier was untuned at the working frequency, but a 60 cycle reject filter network was incorporated to minimize 60 cycle pickup. (Fig No. 22).

The circuit used two pentodes (6AH6's) in cascade , with a triode (6AQ5) cathode follower stage output. Feedback was applied to the cathode of the first stage from the cathode follower. The following table shows the gain and linearity

TABLE X

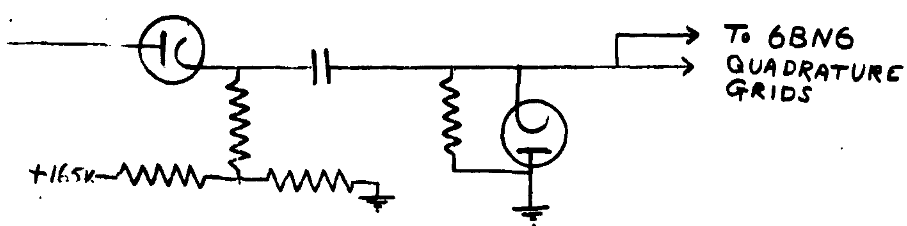
SUMMARY OF TEST RUNS AMPLIFIER NO. 2

Four-Run Average Manual Wedge	Four-Run Average Brown Chart	D.C. Calibration Average Brown Chart Reading	Percentage Difference
1	90	91	1.0%
2	85.05	85.7	0.5
3	80.025	80.6	0.5
4	75.65	75.8	0.2
5	70.35	70.75	0.1
6	65.775	65.85	0.1
7	60.925	60.65	0.1
8	56.25	55.5	0.15
9	51.35	49.4	0.1
10	46.25	44.2	0.2
11	41.325	39.9	0.25
12	36.75	35.7	0.1
13	31.5	30.8	0.075
14	27.025	25.8	0.1
15	22.2	21.0	0.1
16	17.475	16.0	0.1
17	12.7	11.9	0.05
18	8.075	7.5	0.02
19	3.8	3.4	0.01
20	0.925	0.4	0.01

of the amplifier, at 500 c.p.s.:

Input: Peak-to-Peak Volts	Output:Peak-to-Peak Volts	Gain
0.0025	2.5	1000
0.005	5.2	1040
0.01	10.5	1050
0.05	50	1000
0.10	80	800 (beginning to distort)
0.18	100	--- (very distorted)

The 6BN6 gated amplifier stage was originally designed for this amplifier. The quadrature grids of the 6BN6 should start from zero volts, so a D.C. restoring stage and output clipping stage was added to the amplifier stage.



The synchronizing amplifier is a straightforward amplifying limiting circuit, a stage of amplification (6AH6) being followed by a diode limiter, a second stage of amplification and a second limiter, producing good square waves. This is followed by a split load inverter stage, giving two outputs, 90° out of phase, of about 8 volts peak-to-peak.

Tests of the amplifier with a 500-cycle signal from an audio oscillator were made and further tests were made using the automatic balancing system (Fig. 23).

This amplifier was found to be very subject to overloading, causing spillover into the wrong phase. This is shown in Fig. 24, where the response varies with the gain control setting, and in Fig. 25 where percentage error is shown for runs made with different gain settings.

One modified version (Fig. 26), using two double triode amplifiers was built and tested (Fig. 27). This amplifier used two 12AX7 tubes in three triode amplifier stages and a cathode follower output. The measured gain was

25,000X. The noise level was 0.5 volt output. The gain per stage was 35X; without feedback it was 60X (overall gain would be 216,000X). Maximum output per stage is 100 volts peak-to-peak. Maximum output from cathode follower is 30 volts peak-to-peak. This amplifier has too much gain to test with existing systems, but bench tests were made (Fig.21) of gain and linearity, the amplifier started limiting at 100 microvolts input (= 2.0 volts output).

The output from the synchronizing photocell was found to be too small to produce good square waves, and so the synchronizing amplifier was modified. Both pentode amplifier stages preceded the limiting diodes (Fig. 28) and a volume control was added.

The final amplifier is shown schematically in Fig. 29.

This amplifier has good stability and high sensitivity. However, it overloads at such a level that it was found to be unuseable with the present optical photocell system. It overloads with the noise signal from the photomultiplier at room temperature (about 10^{-10} A.)

Amplifier No. 4

Concurrent with the untuned amplifiers Nos. 1, 2 and 3) work was carried out in developing a stable tuned amplifier to work in the A.C. balancing system. Fig 30 shows the first tuned amplifier. The response curve is shown in Fig. 31.

To sharpen the response curve, cathode coupling of the feedback voltage was used, where thé rejection network is driven from a low impedence (Fig. 30b). This gave a much sharper response, but lower gain (Fig. 32).

Next, two twin-tee stages were cascaded and response measured (Fig. 33). This was built into a chasis (Fig. 34) and tests run (Figs. 35 and 36) of linearity and frequency response. Tests were also run on stability and sensitivity, using a simulated signal source from a 1000 cycle signal generator.

Balance was obtained (a) (with gain control at maximum) for 6 microvolt rms input, (b) (with gain control at minimum) for 25 millivolt input.

The stability was measured over a period of ten minutes on each of six input voltages.

Input rms	Output Instability
70 millivolts	±11 microvolts
10 "	±16 "
1 "	±16 "
100 microvolts	±16 "
17 "	±16 "
12 "	±24 "

When this circuit was tried with the automatic balancing system, it behaved poorly. At balance, where there should be zero signal, there was always a signal at 510 cycles. Since the noise must have some component at 510 cycles, the random noise, after passing through the tuned amplifier, gives a pure 510 cycle wave. The possible gain (approx. 10,000X) of this amplifier was found to be too high for present application. The output voltage from the photomultiplier (in the present balancing system) varied from 0.5 to 50 millivolts, and the motor of the Brown potentiometer will move on a signal (D.C.) of about 8 microvolts. From this it appears that a gain of from 10 to 30 should be sufficient with an efficient rectifying system.

The advantages of the tuned amplifier are to be found in the increased signal/noise ratio. Using very high gain amplifiers, the signal is distorted and the 510 cycle component of the noise approaches the signal amplitude.

4. SPECIAL TECHNIQUES

a. Aluminizing Techniques

The requirements for mirrors to be used in ultraviolet reflecting microscopes are much more severe than for mirrors employed in the visible. Not only is high reflectivity desirable in systems that necessarily involve numerous reflections, but scattering must be held to the lowest possible value so as to avoid contaminating the observed spectral characteristics of a small area in a biological section with light from its immediate surroundings. For these reasons it seems to be desirable to compare various techniques for coating mirrors and to measure reflectivity and scattering on the films.

The vacuum system described in earlier reports has been used without significant modification. The forepumps and the diffusion pump were cleaned thoroughly at Distillation Products Industries after two years of intermittent operation. A considerable accumulation of clusters of white needle-shaped crystals of sebacic acid (due to decomposition of Octoil S) was found on the walls of the diffusion pump. Small leaks were discovered where the bleeder valve is connected to the base plate, and at the lead-in electrodes. A glass stopcock was substituted for the metal valve and new neoprene gaskets were installed for the lead-in connections. The system (14-inch bell jar) now attains a pressure of 5×10^{-5} mm in about 20 minutes, and about 1×10^{-5} mm or lower after several hours of pumping.

Aluminizing has been carried out in accordance with standard practice, that is to say evaporating molten aluminum from horizontal spirals of tungsten wire. Tungsten from some sources has not held enough aluminum to give mirror coatings that are essentially opaque. Wire 0.050" in diameter recently obtained from Sylvania has been entirely satisfactory in this respect. Tungsten wire rope from the Bergen Wire Rope Co. has also given excellent results.

There is some indication (Sennett and Scott, J.O.S.A. 40, 203, 1950) that high speed evaporation of aluminum yields coatings with higher reflectivity and larger crystal structure than for slow evaporation. This suggests the possibility that scattering from such coats will be less than when evaporation is carried out more slowly. Accordingly, experiments have been carried out on several possible methods for accelerated evaporation.

Induction heating has been attempted, using a 0.3 and 10 MC generator with one KVA output and a copper coil. These experiments, carried out in air, failed to heat aluminum to a temperature high enough for evaporation. A higher frequency might be successful.

Some experiments have been made with an arc between an aluminum drop on graphite and a tungsten electrode, with currents of about 25-40 amperes D.C. Evidence from other work (see Finkelnburg "Physik u. Technik des Hochstromkohlebogens," Akad. Verl. - Ges. Leipzig, 1944) indicates that atomic particles may be ejected perpendicular to the end surfaces of an electrode, while larger particles are ejected in other directions. Experiments will also be made with a condenser discharge between aluminum electrodes.

b. <u>Preparation of Sections for Spectral Studies</u>

The requirements for mounting biological material that is to be examined by microspectroscopic methods are (1) that it be as thin as possible, preferably not more than a micron thick, and (2) that it be subjected to the absolute minimum of contact with chemical reagents of any kind. This suggests that cold sectioning, followed by drying of the sections in a vacuum at low temperature, is the method of choice. Until this can be accomplished, freezing and drying, followed by embedding in paraffin for sectioning, and washing out of the paraffin with organic solvents appears to be the best method to employ.

Experiments are planned for sectioning with an A-O microtome at various low temperatures, between -15° and -40° C. Studies have been made of the performance of a Frigidaire deep freeze box. When operated continuously, it can attain a temperature of -40° C but it does not have enough reserve capacity to permit controls to pass through the walls for operating the microtome. Several other commercial boxes have been investigated. A large cold box, used during the war for storage of blood samples, attains -50°C with a 2 H.P. compressor that has been transferred from another ONR contract, but the difficulties about modifying doors and walls for the entry of controls is such that it seems best to construct an experimental box expressly for this application. Accordingly, such a box, measuring 21" x 21" x21" inside will be made. It will be possible to use it with the open face either at the top (which is obviously best from the point of view of reducing air exchange) or at one side (which may simplify operation).

Plans are being made for constructing a freezing-drying system that will permit drying in a vacuum at temperatures down to about -78° C, with provision for following the weight of the specimen as it dries. It is to be hoped that a satisfactory cycle of drying can be worked out, with assurance that drying is essentially complete before the temperature is raised for embedding in paraffin. Experiments described in earlier reports show that present technique may be unsatisfactory in this respect.

III. PLANS FOR FUTURE WORK

1. EQUIPMENT

a. The equipment for comparing spectral energy of ultraviolet sources and spectral response of receivers, will be completed, and the desired measurements will be made. This can probably be accomplished during the summer and fall of 1953.

b. The performance of the A.C. balancing amplifier will be further assessed, and its performance will be compared with that of the present D.C. system. Two stable D.C. amplifiers will be built and employed in a monitoring system, with those sources which show enough instability to require monitoring. If the A.C. system shows equal performance, it may be desirable to substitute it.

c. The Burch microscope will be installed and tested as soon as it is delivered.

d. A monitoring pulse counting system will be assembled and tested.

e. Mountings to permit operating the R.C.A., E.M.I., and Schaetti photomultipliers at low temperature will be constructed, and the dark current of each of these tubes will be measured over a wide range of temperature.

f. An overall system for microspectroscopy will be assembled from component units that are now available, so that spectral absorption curves can be measured.

g. A cathode ray tube will be provided to permit direct viewing of the absorption spectrum of any selected small area in the field of the microscope.

h. The flux required at various wavelengths to give a satisfactory visual display of the ultraviolet, when using the R.C.A. industrial television system with a Vidicon tube, will be measured.

2. SPECIAL TECHNIQUES

Further studies will be made of methods for aluminizing mirrors, and an optical system will be built to permit reasonably reliable measurements of reflectivity and of scattering from mirror coatings.

Methods for cutting extremely thin sections of biological tissues will be investigated further, using a cold box in which the temperature can be controlled.

A system for making further studies of drying in a vacuum at low temperatures, as a function of time, will be constructed.

3. BIOLOGICAL APPLICATIONS

As indicated above, an overall system for microspectroscopy is now being assembled for studies of biological cells.

Spectral absorption studies will be undertaken on isolated cells, including leucocytes and erythrocytes. Consideration is being given to studying thin living cells, if any can be grown in tissue culture thin enough to make it feasible to achieve a useful level of optical resolution.

IV. STAFF

During the period covered by this report the operating staff of the project has included the following individuals:

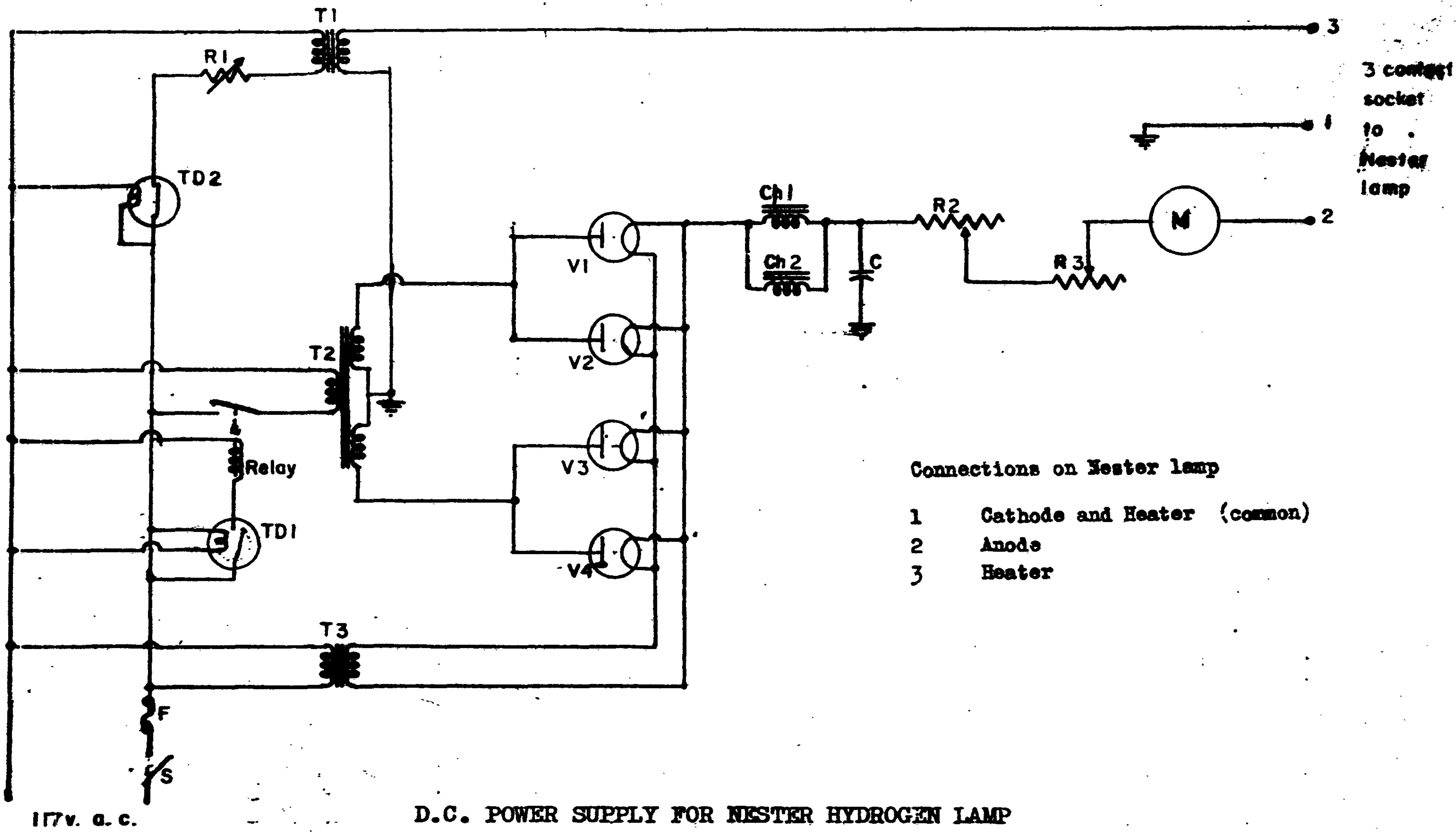
Theodore Dunham, Jr.	Principal Investigator
George R. Mott	Research Associate - Electronics (Part Time)
Robert Blakney	Research Associate - Optics (Part Time)
Crewdson D. Scott	Research Assistant
Robert Brown	Research Assistant
Reinhold Gerharz	Research Assistant
James A. Gregg	Research Assistant (Part Time)
Lawrence Aman	Instrument Maker
Michael Silverberg	Laboratory Technician (Part Time)
Donald McLeod	Laboratory Technician (Part Time)
Ruth J. Pirson	Secretary and Research Assistant

V. GOVERNMENT-OWNED CAPITAL EQUIPMENT LOANED BY ONR FOR USE UNDER CONTRACT N6onr-241, TASK ORDER 13

1 Hewlett - Packard Audio Signal Generator
1 Jackson Audio Oscillator
1 Esterline - Angus Graphic Ammeter (Model AW)
1 Print Dryer (Pako Corp.)
1 Lathe, Craftman, 9" swing
1 Milling Machine, Burke No. 12, Model 126A
1 Brown Potentiometer - Recorder, Model 151321
1 Drill Press, Walker Turner, 15"
1 Arbor Press, Manley
1 Vise, 3½", swivel base
1 Spyglass, 16-power, Mark I
1 Typewriter, Underwood, Serial No. 888325
Miscellaneous Electronic Parts
1 Binoculars, 8 x 56
1 Generator, motor, 23.5 H.P., output D.C., 125 volts 120 amperes
1 Generator, motor, 1/4 H.P., output D.C., 0.020 amperes
1 Machine, Engraving
1 Machine, Grinder, Internal
Miscellaneous Microscope elements (Bausch and Lomb)
1 Motor, D.C., 1/3 H.P.
1 Tocco Heat Gun, Serial No. HG 007
1 Oscilloscope (Allen B. Dumont Laboratories) Serial No. 2410
1 Compressor (Servel Co.) Serial No. 543-61712
1 Test Rack (Hazeltine Electronics Corp.) Model TE-1000B
1 Special Relay Lens (Bausch and Lomb) Serial No. KS-7325

Theodore Dunhan, Jr.
Principal Investigator

June 30, 1953
Rochester, N.Y.



Connections on Nester lamp

1 Cathode and Heater (common)
2 Anode
3 Heater

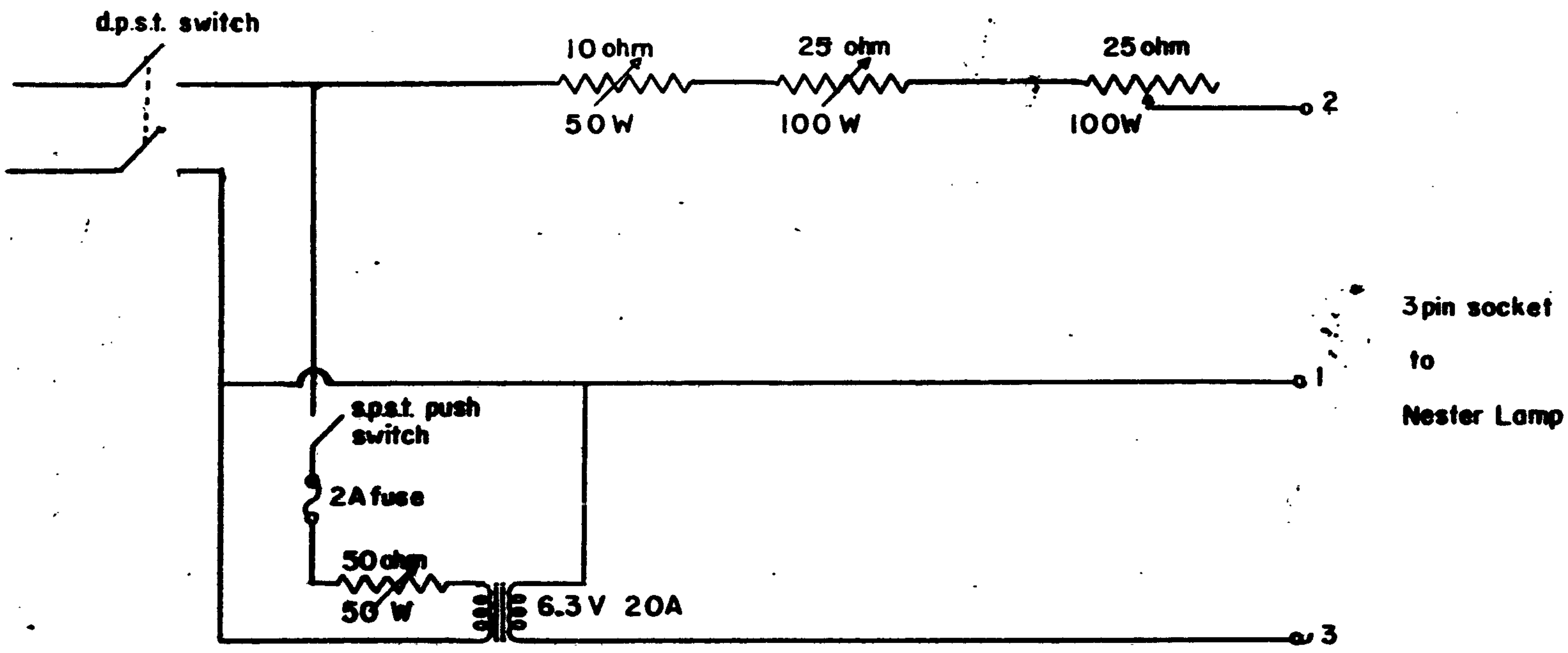
D.C. POWER SUPPLY FOR NESTER HYDROGEN LAMP

FIGURE 1

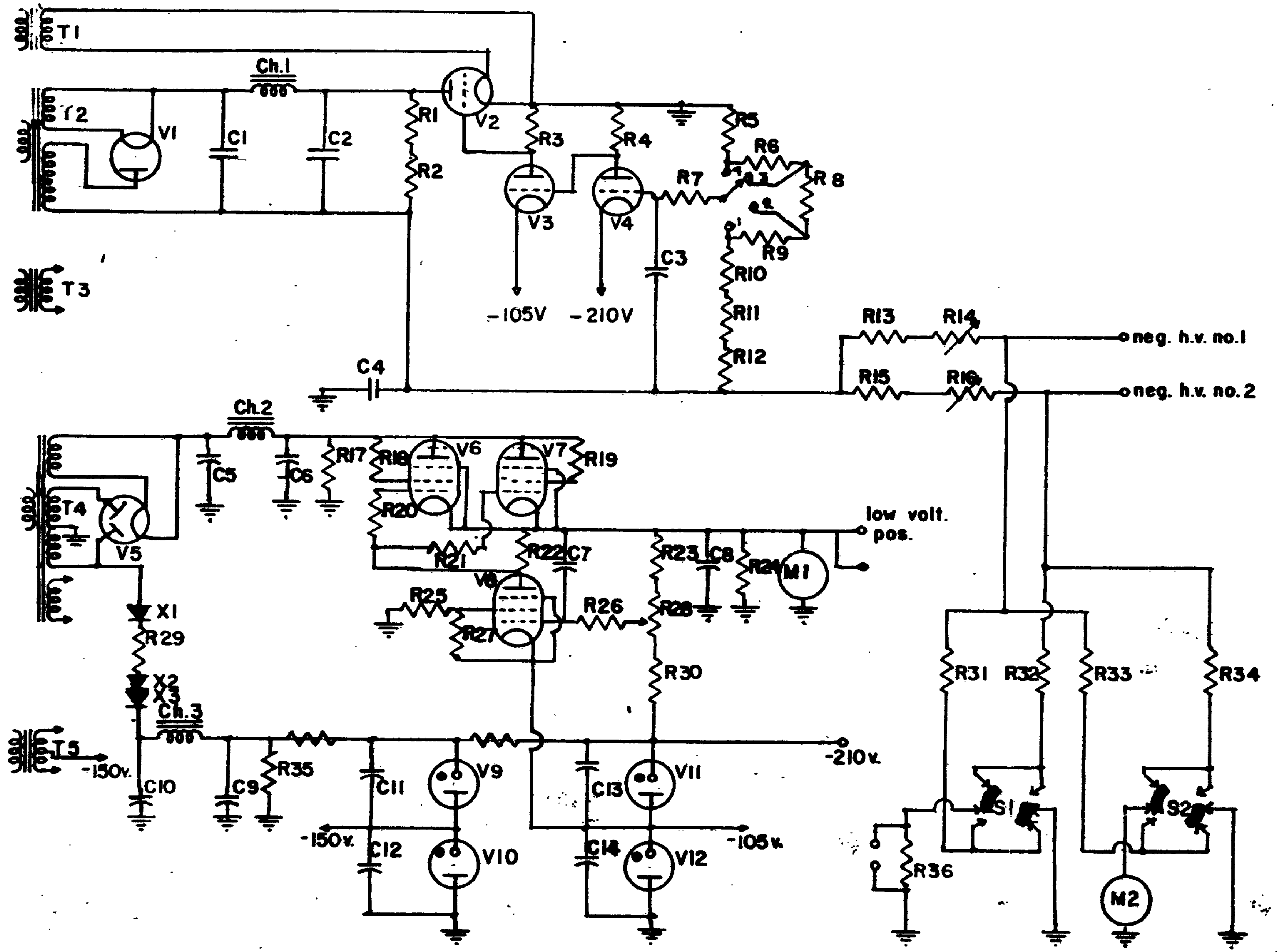
LIST OF PARTS FOR NESTER LAMP POWER SUPPLY

T1	Transformer, pri. 117 V; sec. 6.3 V, 20 A (Stancor P6309)
T2	Transformer, pri. 117 V; sec. 2C 240 V, 1.56 A (G.E. Hipersil)
T3	Transformer, pri. 117 V; sec. 2.5 V, 20 A (UTC S58)
Ch.1 & Ch.2	Chokes, 0.5H 0.5A
Relay	s.p.s.t. normally open, 117 V, A.C. coil
TD1	Thermal delay switch, 60 sec. normally open
TD2	Thermal delay switch, 90 sec. normally closed
V1, V2, V3, V4	866A Mercury vapor rectifier tubes
F	5A Littlefuse Slo-Blo fuse
S	s.p.s.t. 10A switch
M	0-1.5A Meter
C	40 mfd. 250 V, electrolytic condenser
R1	50 Ohm 50 W variable resistor (adjust for 15A filament)
R2	150 Ohm 200 W rheostat
R3	15 Ohm 20 W rheostat

Figure 1a



A.C. POWER SUPPLY FOR NESTER HYDROGEN LAMP.
FIGURE 2



SCHEMATIC DIAGRAM, 500 to 1500 volt REGULATED POWER SUPPLY

FIGURE 3

PARTS LIST FOR 500 to 1500 VOLT REGULATED POWER SUPPLY

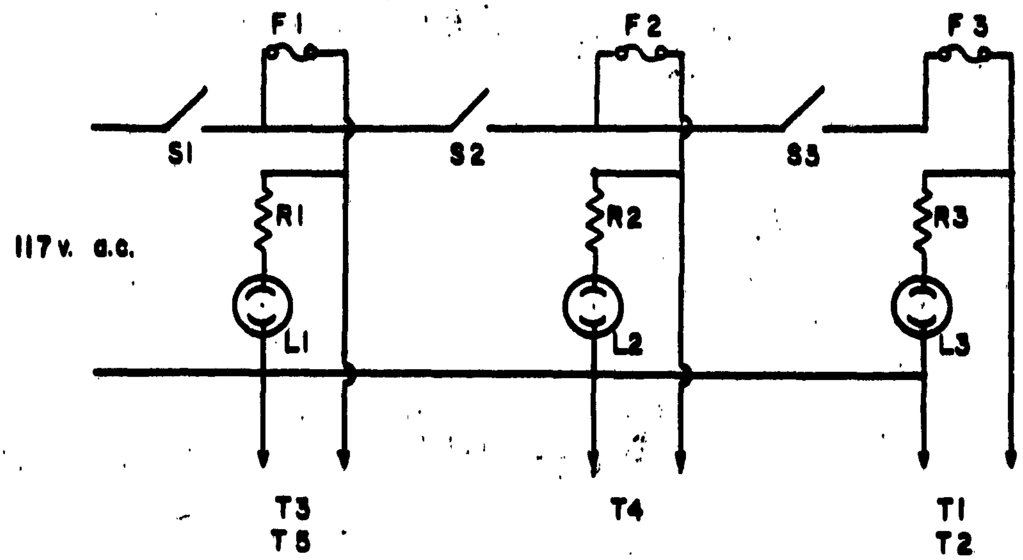
T1	Transformer, Thordarson T21F10 (6.3 V 10 A secondary) Filament V2
T2	Transformer, Thordarson TV24R92 (2400 V 10 mA 2.5 V 1.75 mA; secondaries)
T3	Transformer, Thordarson T21F10 (6.3 V 10 A secondary) Filaments V6 and V7
T4	Transformer, Stancor P6315 (370-0-370 V 275 mA; 5 V 3A; 6.3 V 7 A secondaries)
T5	Transformer, Thordarson T21F08 (6.3 V 1A secondary)
Ch. 1	Choke, Thordarson T20C50 (200 H. 10 mA)
Ch. 2	Choke, Stancor, C1401 (2- 10H, 200 - 20 mA)
Ch. 3	Choke, Stancor, C1001 (10H 80 mA)
X1, X2, X3	Federal selenium rectifiers, 100 mA @ 130 V.
V1	2x2 Rectifier tube
V2	3C24 Triode (Eimac)
V3, V4	6SL7 Double triode tube
V5	5U4G Rectifier tube
V6, V7	5Y6G Pentode tubes
V8	6SJ7 Pentode tube
V9, V10	OD3 Voltage regulator tubes
V11, V12	OC3 Voltage regulator tubes
M1	0-300 Volt meter, 1000 ohms/volt
M2	0-200 Microamp meter
S1, S2	Centralab wafer switch, shorting type
C1, C2	0.25 mfd 3 Kv condenser
C3	0.01 mfd 1.5 Kv condenser
C4	2 mfd 3 Kv condenser
C5, C6	16 mfd 600 V electrolytic condensers
C7	0.1 mfd 600 V condenser
C8, C9	40 mfd 450 V electrolytic condensers
C10	16 mfd 450 V electrolytic condenser
C11, C12, C13, C14	0.05 mfd condensers
R1, R2	5 Megohm
R3, R4	470 K 1 W
R5	900 K 10 W Nobleloy
R6	300 K 1 W Nobleloy

Figure 2a

PARTS LIST FOR 500 to 1500 VOLT REGULATED POWER SUPPLY CONTINUED

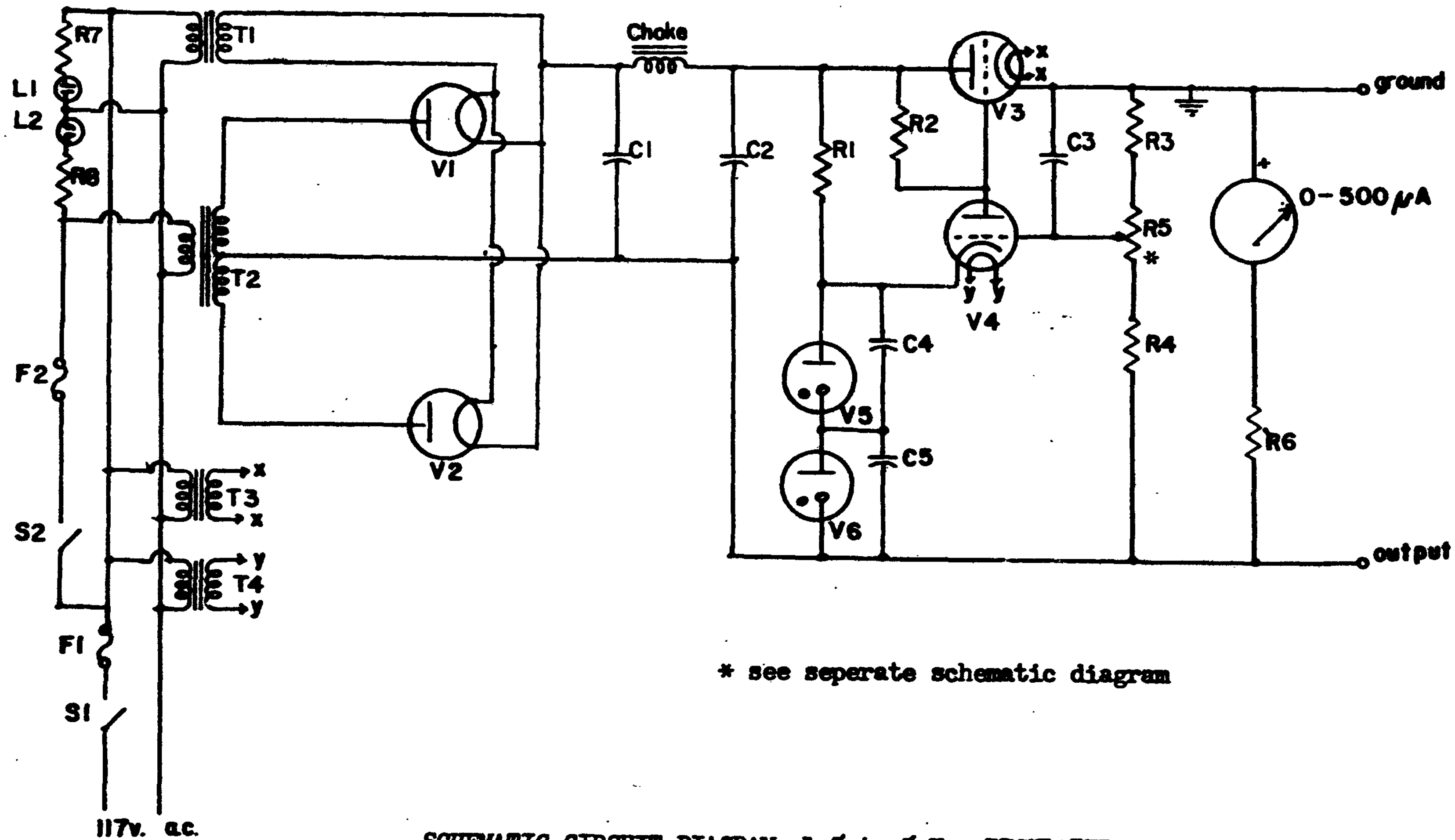
R7	100 K
R8	300 K 1W Nobleloy
R9	600 K 1 W Nobleloy
R10	900 K 1 W Nobleloy
R11	2 Megohm 2 W Nobleloy
R12	4 Megohm 2 W Nobleloy
R13	200 K 1W Nobleloy
R14	500 K Potentiometer
R15	200 K 1 W Nobleloy
R16	500 K Potentiometer
R17	60 K 10 W w.w.
R18	470 Ohm 2 W
R19	470 Ohm 2 W
R20, R21	100 Ohm 1 W
R22	820 K
R23	200 K 1 W Nobleloy
R24	47 K 2 W
R25	27 K
R26	100 K
R27	27K
R28	100 K w.w. Potentiometer
R29	2K 200 W w.w.
R30	75 K 1 W Nobleloy
R31, 32, 33, 34	10 Megohm 1 W Nobleloys
R35	60 K 1 W w.w.
R36	10 K 1 W Nobleloy

Figure 3a



F1 2A fuse
F2 5A "
F3 1A "
R1, R2 & R3 120K resistors
L1, L2 & L3 NE51 lamps
S1, S2 & S3 5A s.p.s.t. toggle switches.

POWER CONNECTIONS, 500-1500 VOLT POWER SUPPLY.
Figure 4



* see seperate schematic diagram

SCHEMATIC CIRCUIT DIAGRAM, 1.5 to 5 Kv. REGULATED POWER SUPPLY

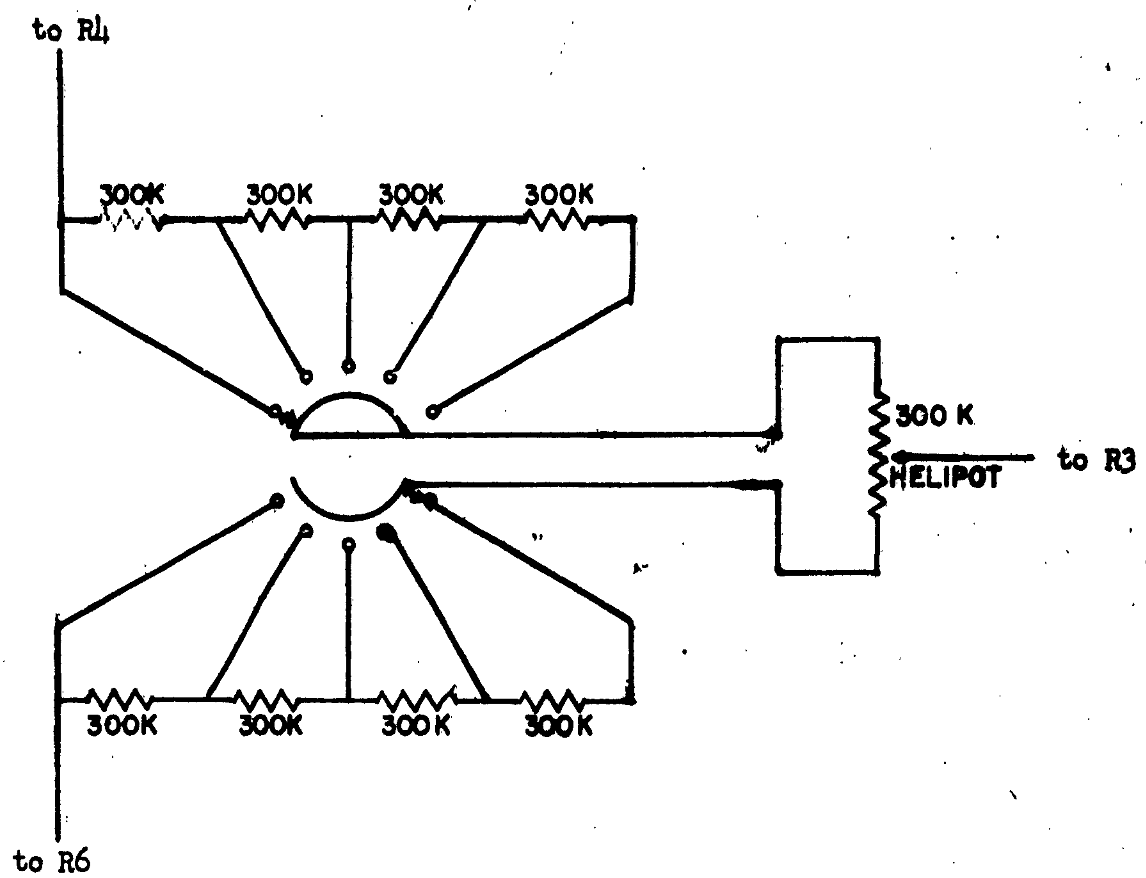
FIGURE 5

COMPONENT PARTS LIST, 1.5 to 5 Kv. REGULATED POWER SUPPLY

T1	Transformer, pri. 117 V; sec. 2.5 V, 10 A, 10 Kv. insulation (Stancor P3060)
T2	Transformer, pri. 117 V; 4600-4200-0-4200-4600V 35 mA (Arjac)
T3	Transformer, pri. 117 V; sec. 6.3 V, 1.2 A (Stancor P6134)
T4	Transformer, pri. 117 V; sec. 6.3 V, 1.2 A, 5 Kv insulation (Stancor P8190)
Choke	450H @ 5 mA (UTC S23)
V1 & V2	RK72 Rectifier tubes
V3 & V4	2C53 High voltage triode tubes
V5 & V6	5651 Voltage reference tubes
C1 & C2	0.5 mfd. 7200 V condenser (2 @ 1mfd. 3600 V in series)
C3	0.01 mfd. 6000 V tubular condenser
C4 & C5	0.002 mfd. 300 V tubular condenser
R1	4.2 Meg. 18 W (9 @ 470 K 2 W in series)
*R2	5 Meg. 10 W (5 @ 1 meg. 2 W 1% Nobleloy in series)
*R3	8.2 Meg. 8 W (4 @ 2 meg. 2 W, 1 @ 200 K 1 W, 1% Nobleloy)
*R4	300 K. 1 W 1% Nobleloy
*R5	1.5 Meg. variable (see separate diagram)
*R6	10 Meg. 10 W (5 @ 2 meg. 2 W 1% Nobleloy)
R7 & R8	200 K ½ W resistors
S1 & S2	115 V, 10 A, s.p.s.t. toggle switches
L1 & L2	NE51, Neon pilot lamps
F1	5 A Littlefuse
F2	2 A Littlefuse

* Precision Resistors

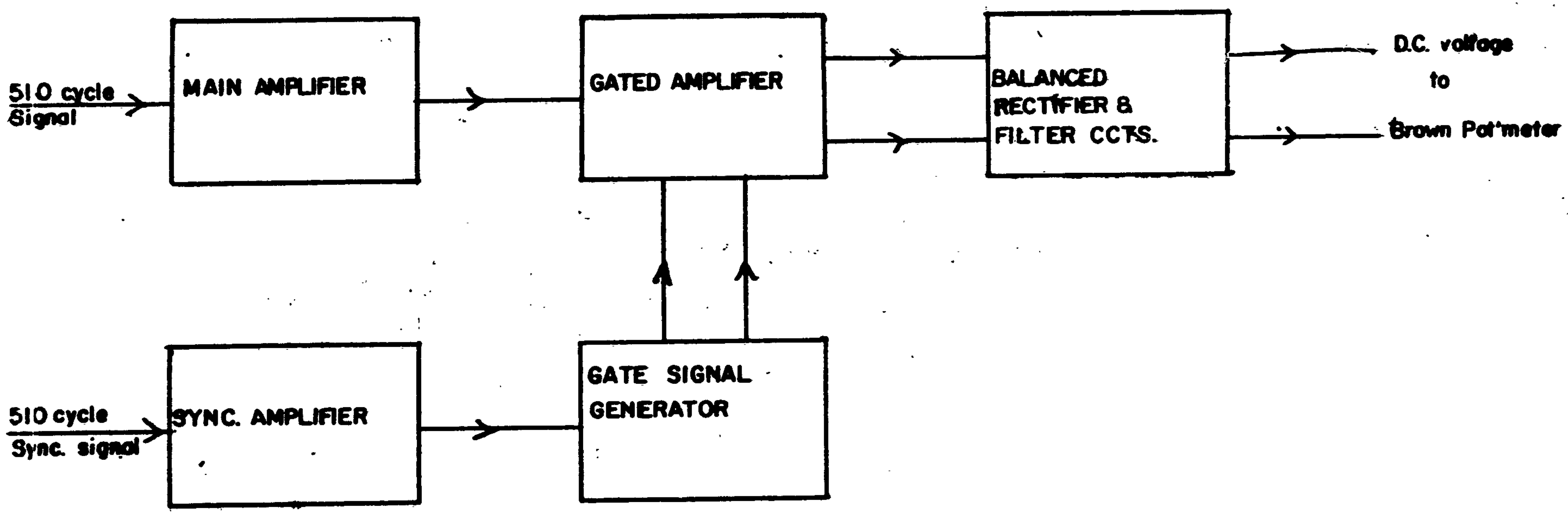
Figure 5a



All resistors are 300K 1W 1% Noblelcy

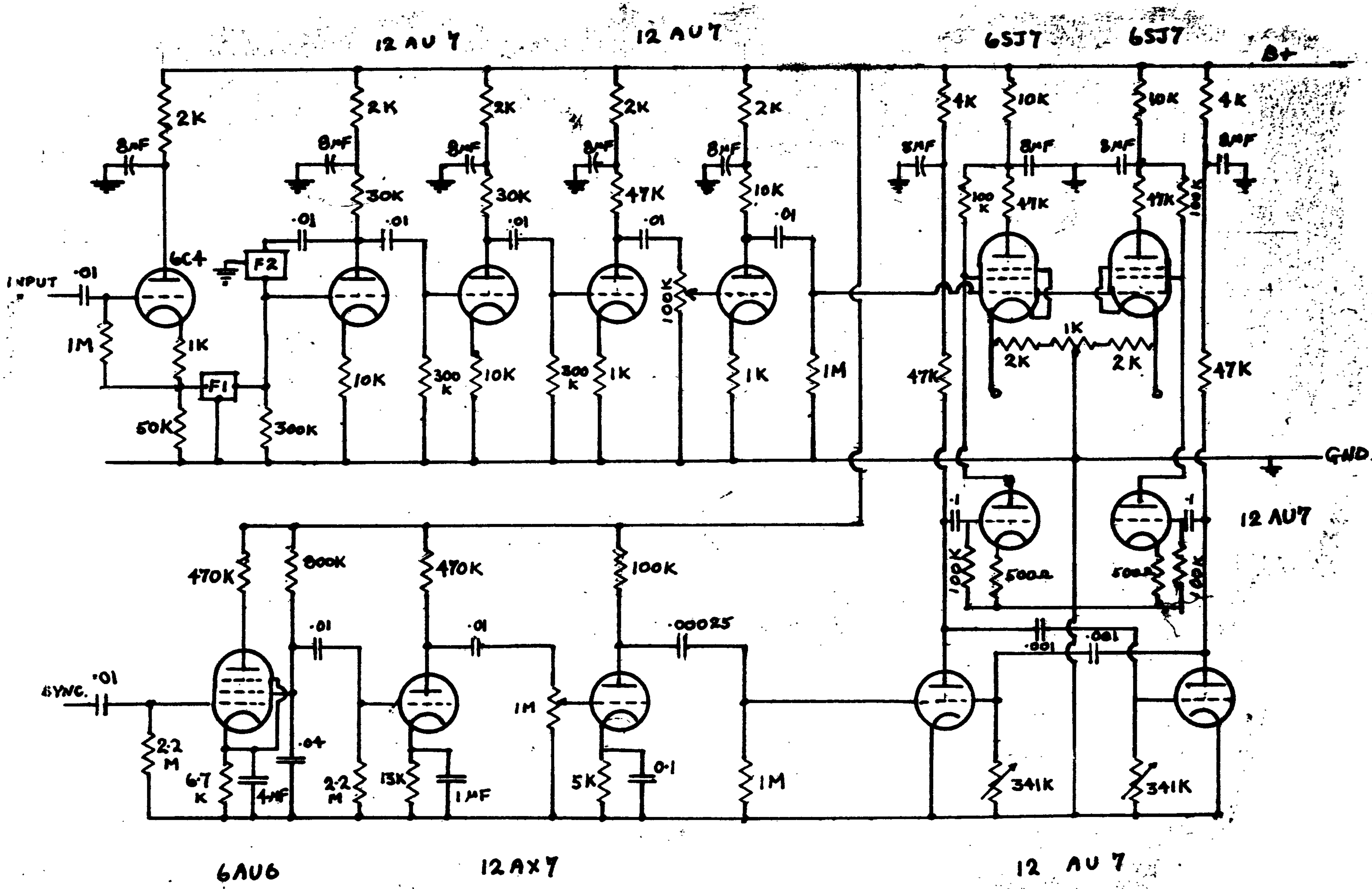
SCHEMATIC DIAGRAM R5 POTENTIOMETER ON 1.5 to 5 Kv. POWER SUPPLY

Figure 6



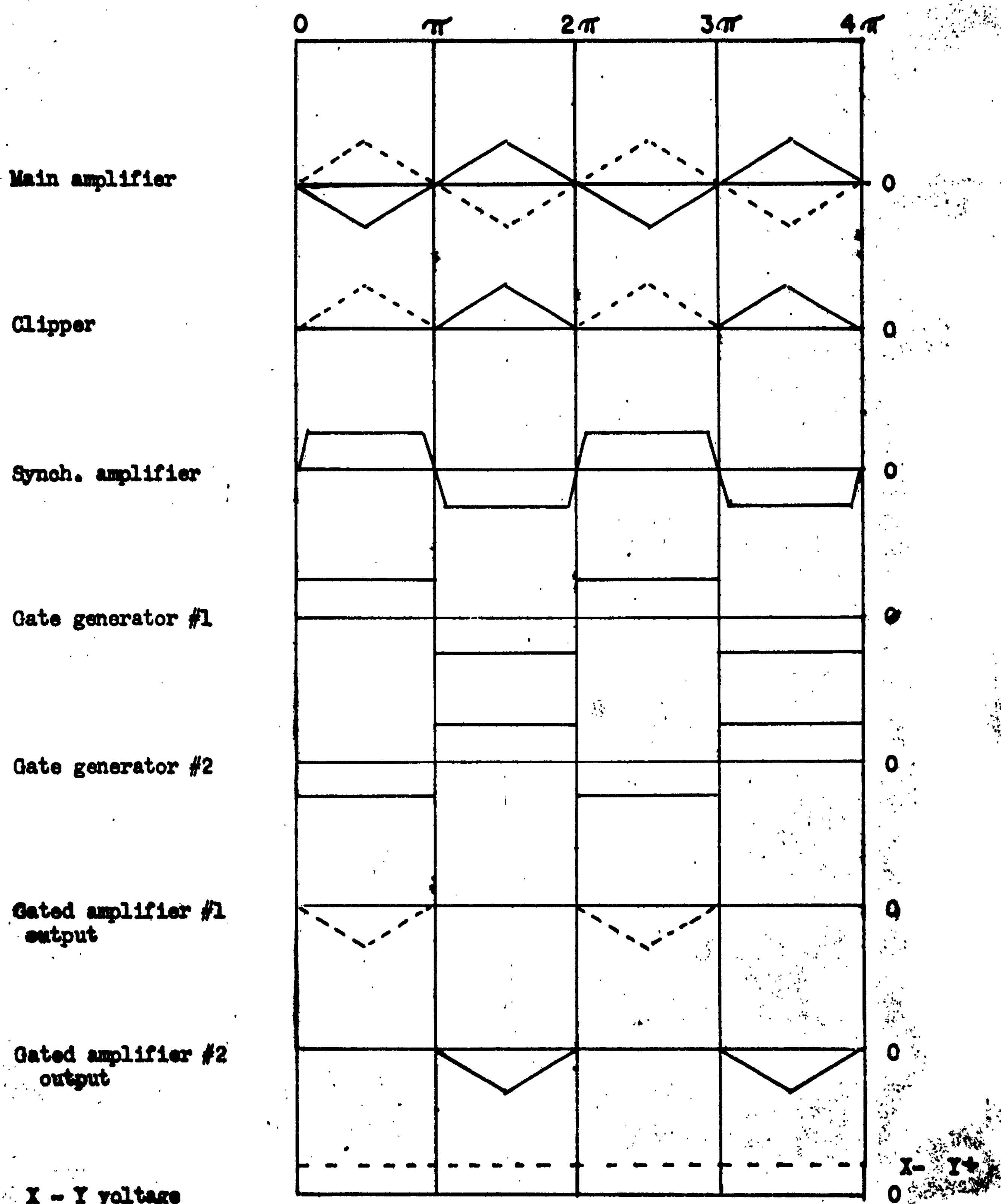
BLOCK DIAGRAM, BALANCING AMPLIFIER

FIGURE 7



Schematic Diagram, A.C. Balancing Amplifier
FIGURE 5

WAVE FORMS PRESENT IN BALANCING AMPLIFIER (IDEALIZED)
FOR OPPOSITE STATES OF UNBALANCE.



Solid lines indicate unbalance in one direction dashed lines in the other.

Figure 9

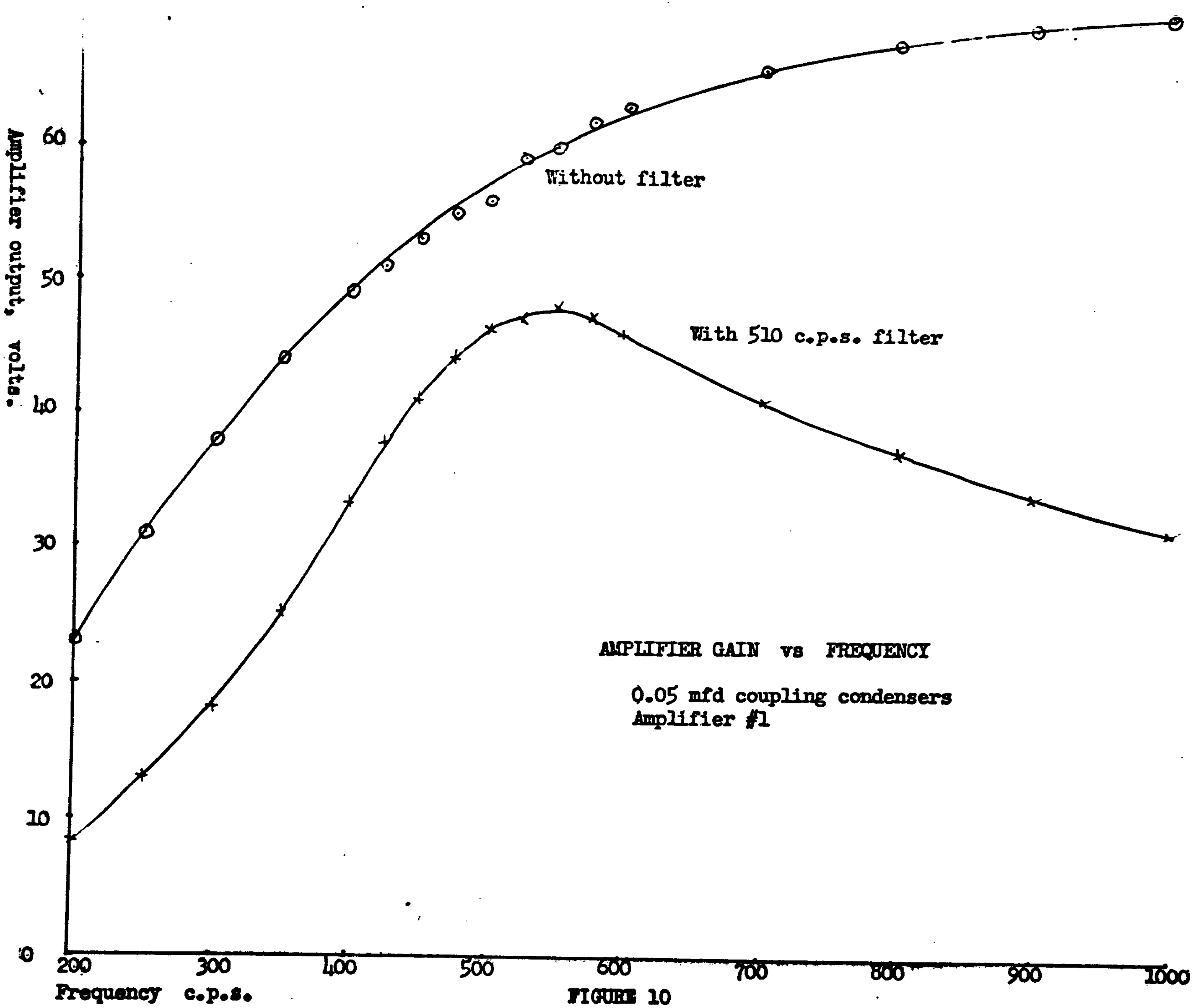

Amplifier output, volts.
60
50
40
30
20
10
0
200
300
400
500
600
700
800
900
1000
Frequency c.p.s.
Without filter
With 510 c.p.s. filter
AMPLIFIER GAIN vs FREQUENCY
0.05 mfd coupling condensers
Amplifier #1

FIGURE 10

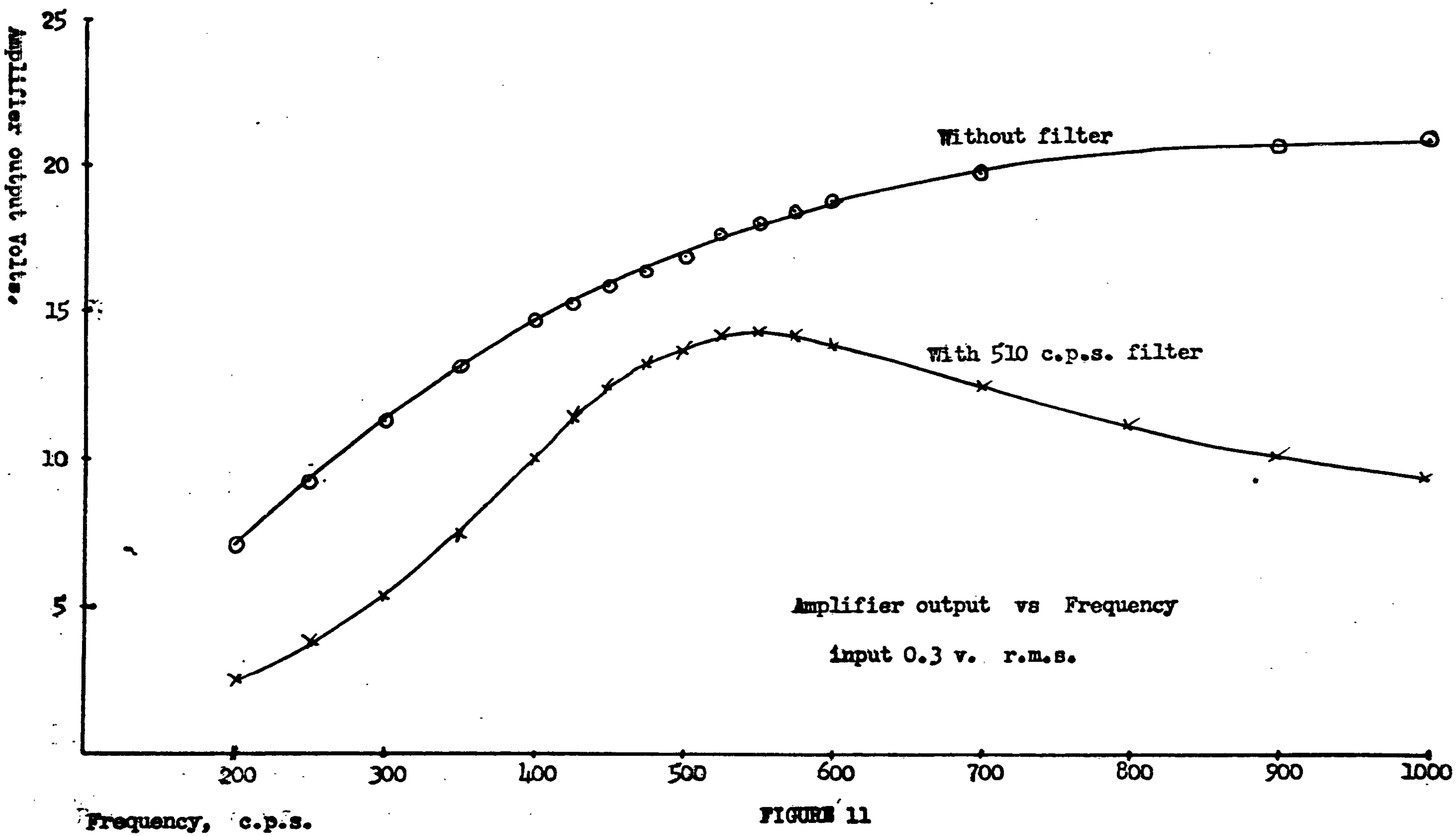
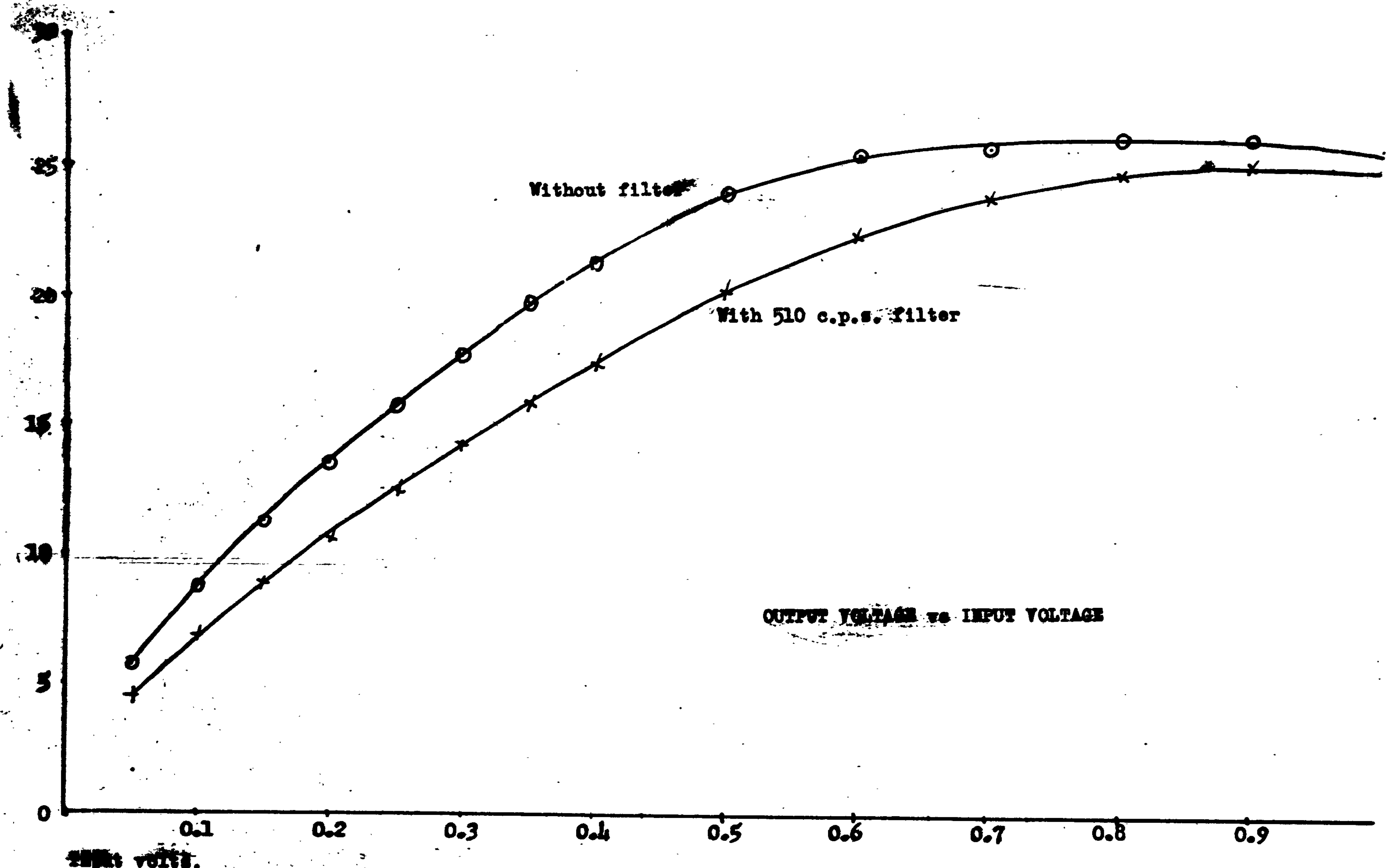

25
20
15
10
5
Amplifier output Volts.
Without filter
With 510 c.p.s. filter
Amplifier output vs Frequency
input 0.3 v. r.m.s.
200
300
400
500
600
700
800
900
1000
Frequency, c.p.s.

FIGURE 11



LINEARITY AMPLIFIER #1
FIGURE 12

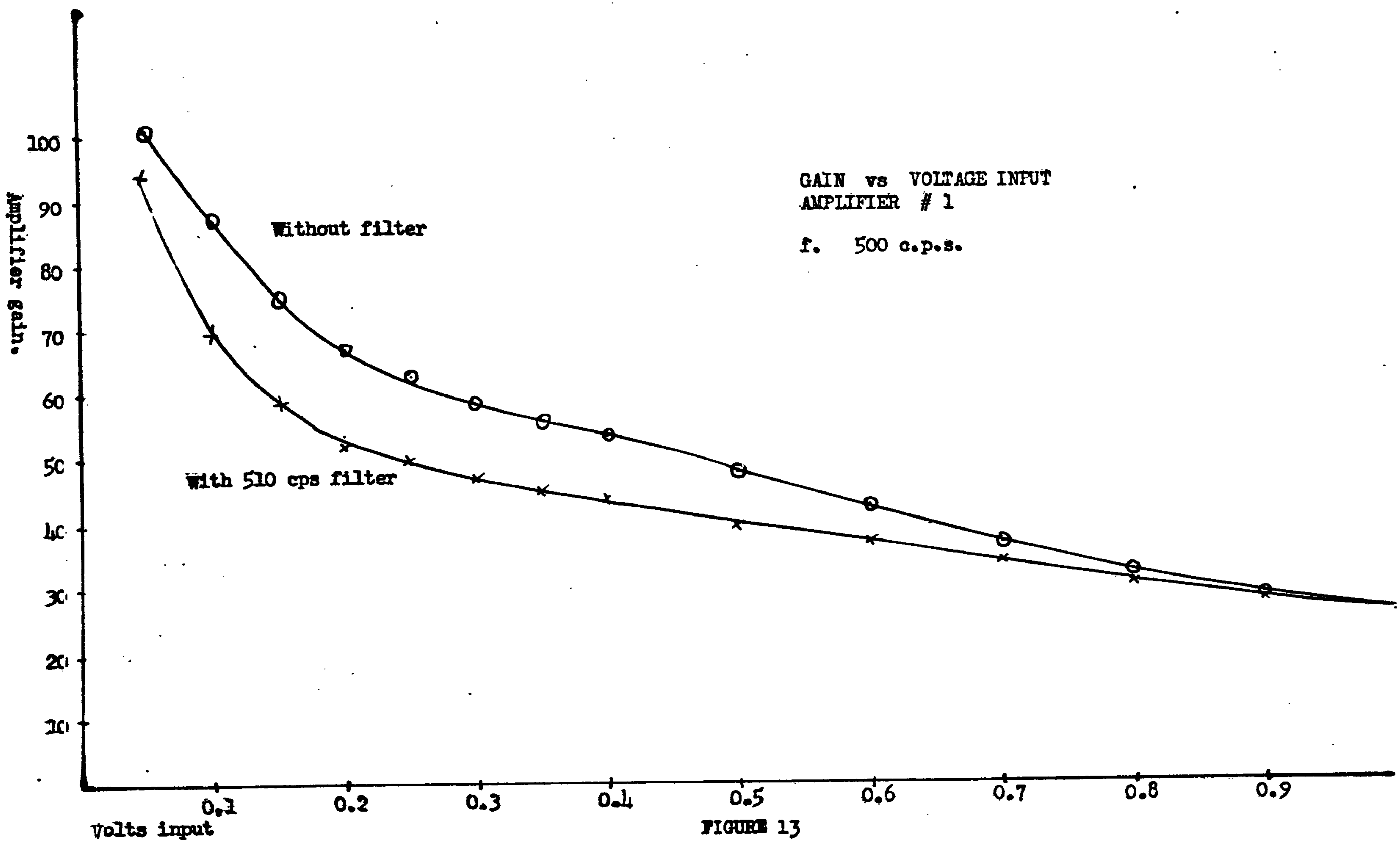
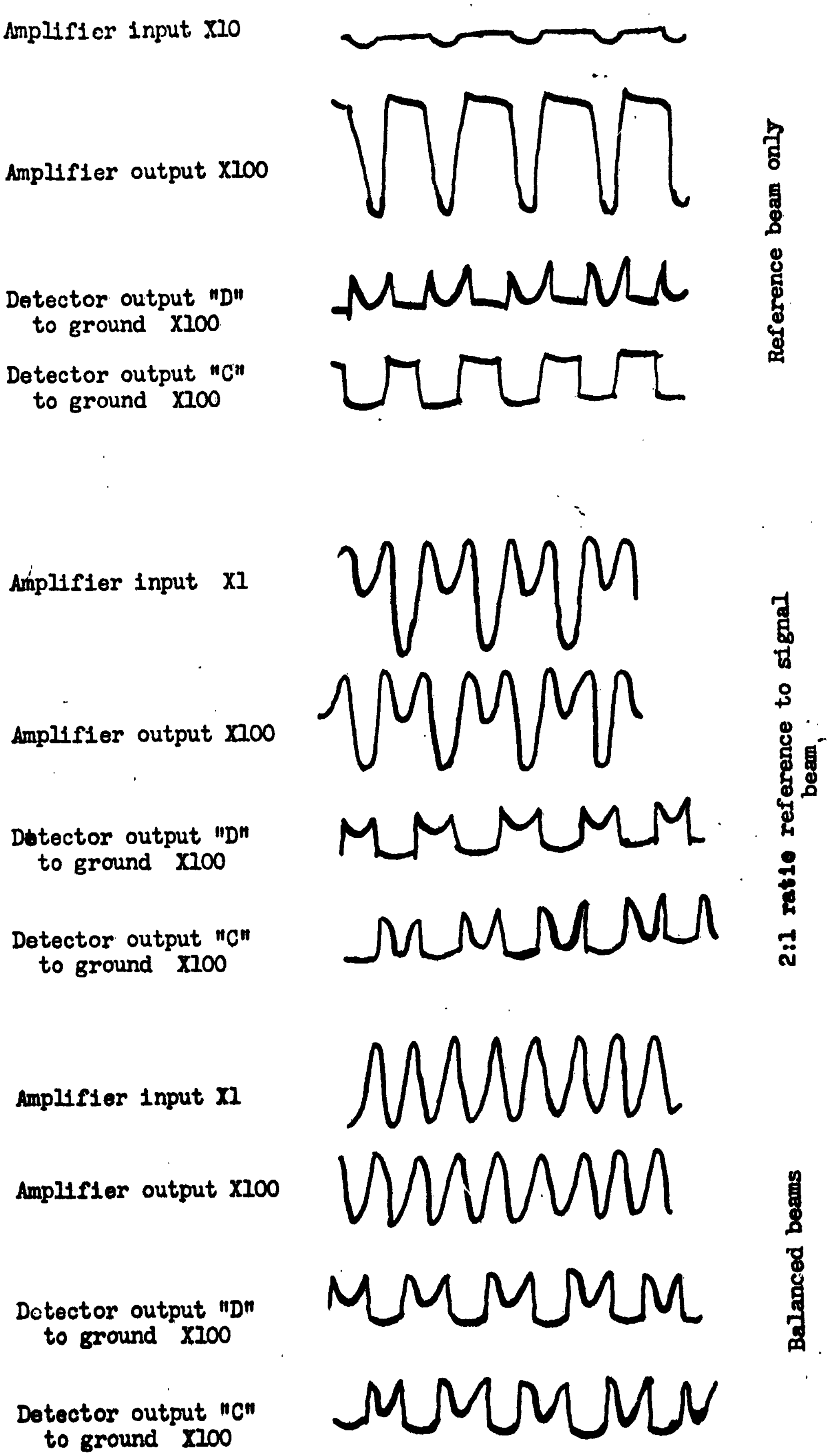
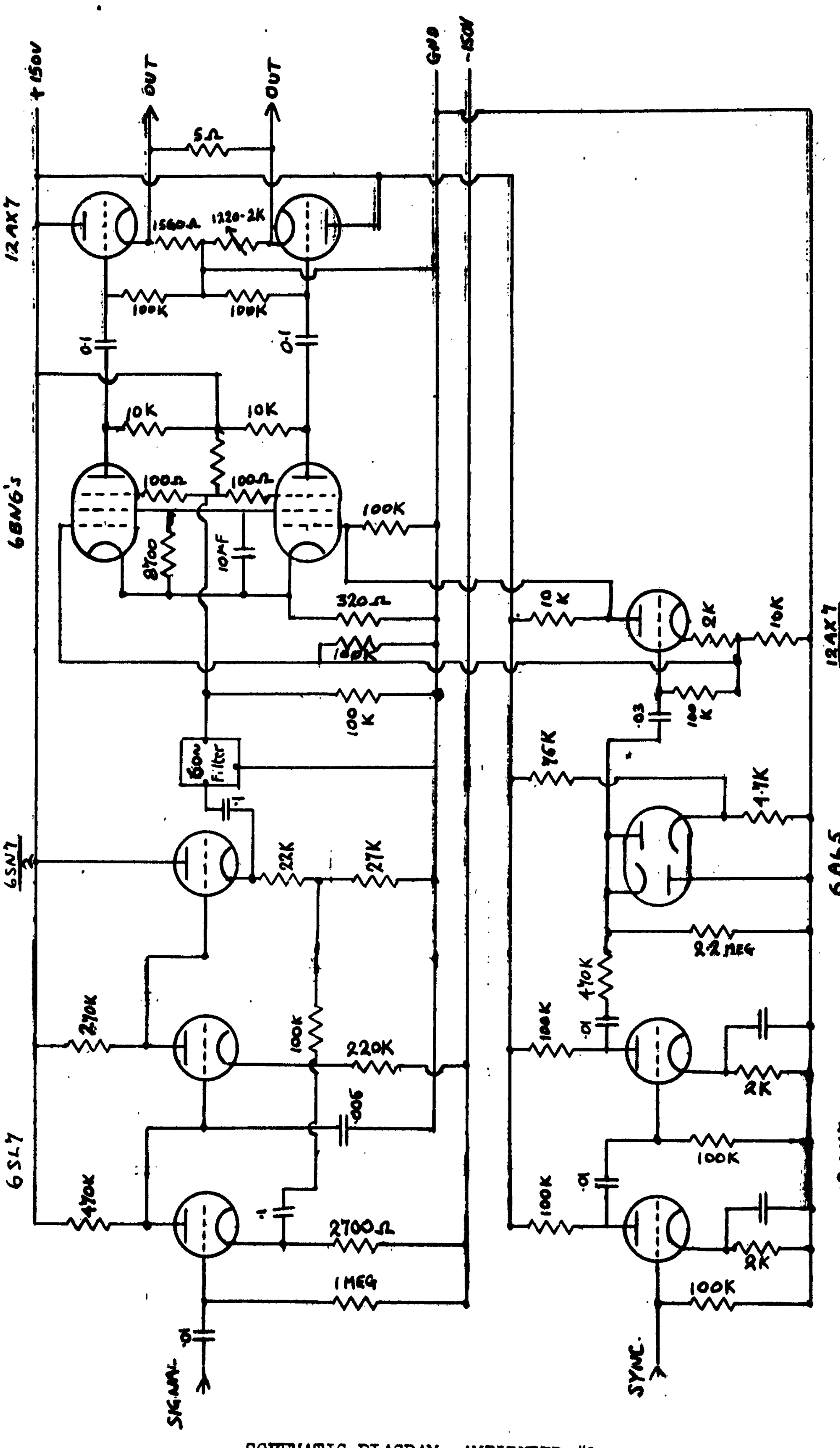

GAIN vs VOLTAGE INPUT
AMPLIFIER # 1
f. 500 c.p.s.
Without filter
With 510 cps filter
Amplifier gain.
100
90
80
70
60
50
40
30
20
10
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Volts input

FIGURE 13

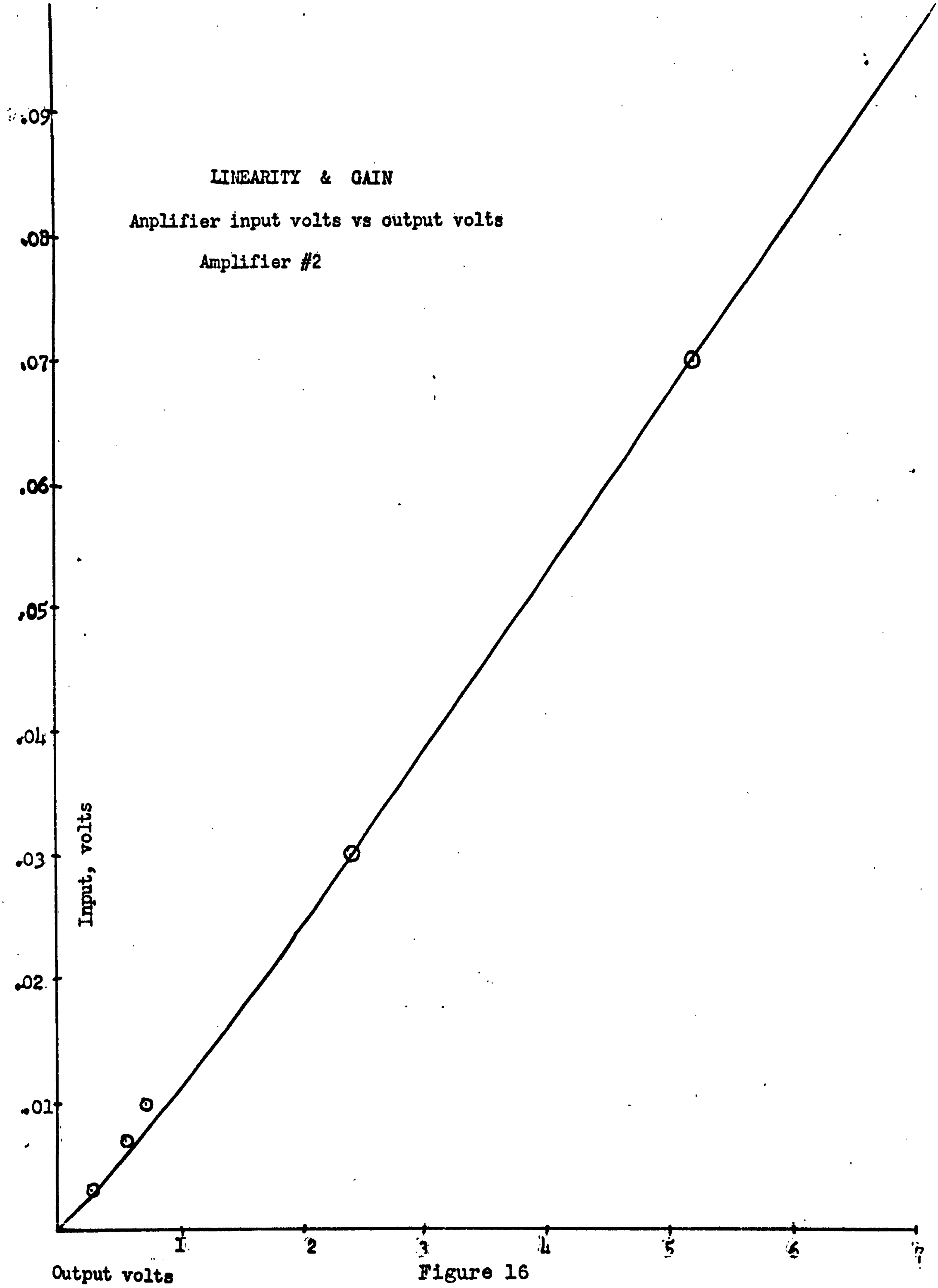


OSCILLOSCOPE PERFORMANCE RECORDS, AMPLIFIER #1.
FIGURE 14



SCHEMATIC DIAGRAM, AMPLIFIER #2
FIGURE 15

SCHEMATIC DIAGRAM, AMPLIFIER #2


LINEARITY & GAIN
Anplifier input volts vs output volts
Amplifier #2
Input, volts
.09
.08
.07
.06
.05
.04
.03
.02
.01
1
2
3
4
5
6
7
Output volts
Figure 16

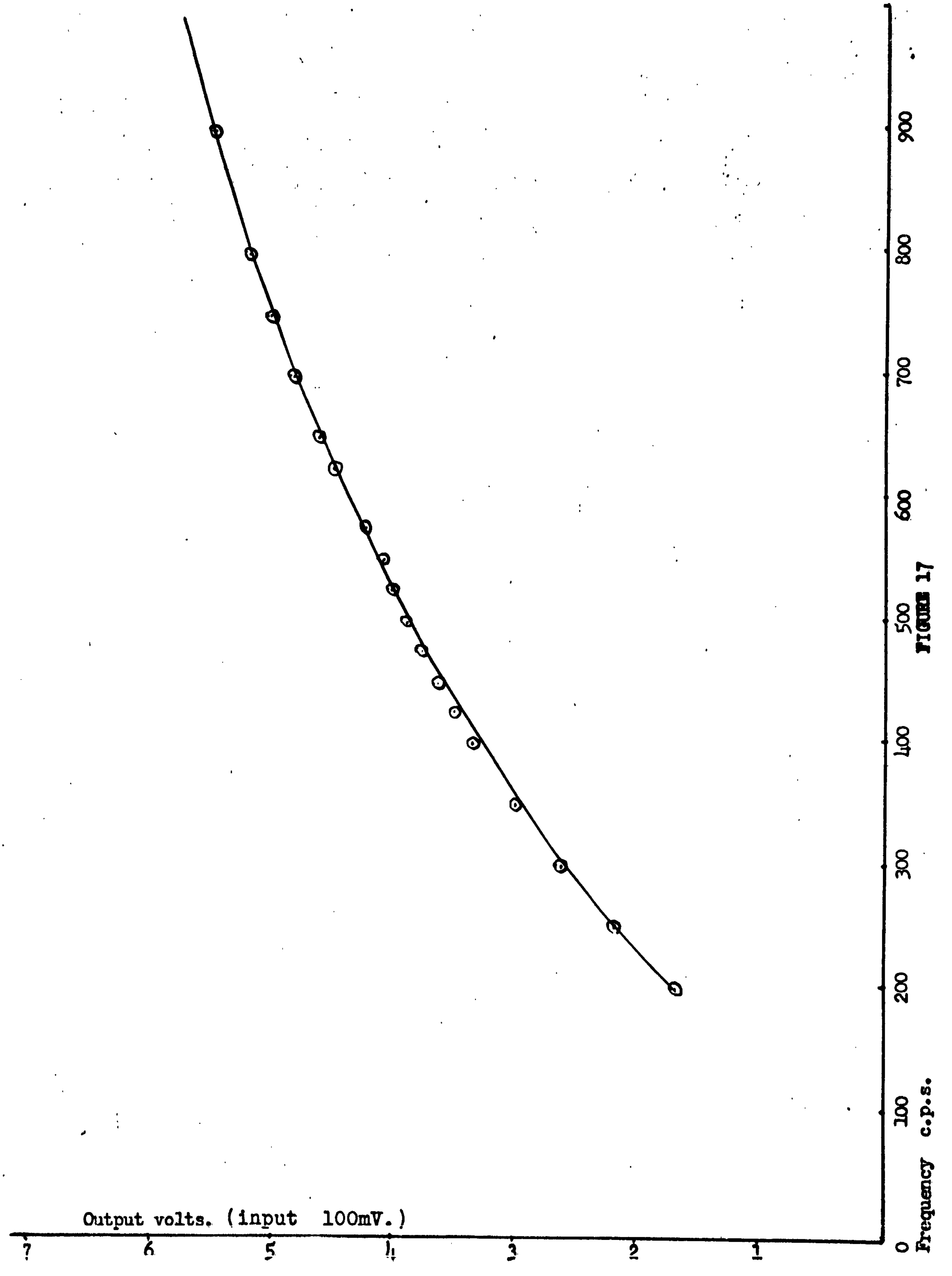
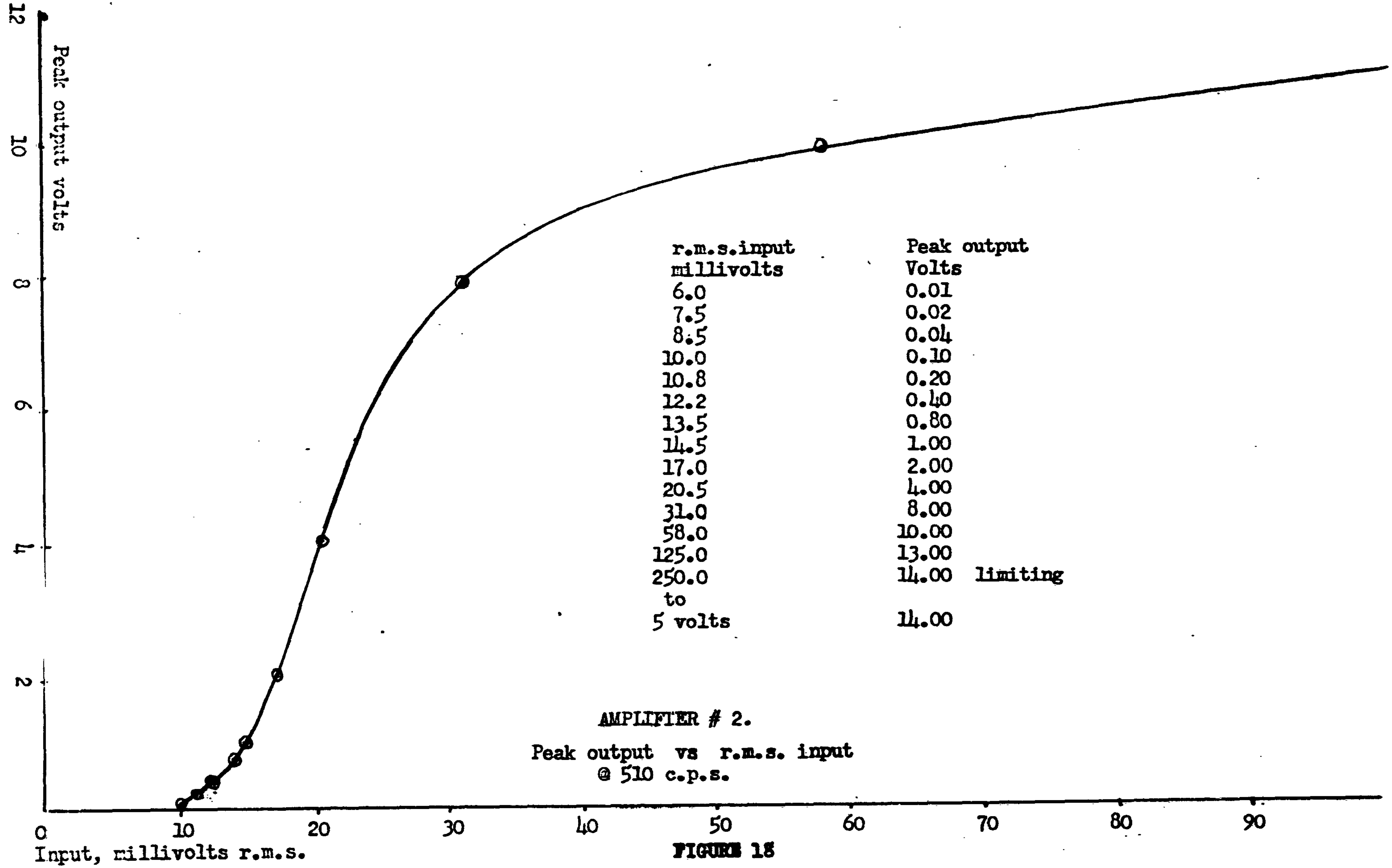


FIGURE 17

FREQUENCY RESPONSE, AMPLIFIER #2



r.m.s.input millivolts	Peak output Volts	
6.0	0.01	
7.5	0.02	
8.5	0.04	
10.0	0.10	
10.8	0.20	
12.2	0.40	
13.5	0.80	
14.5	1.00	
17.0	2.00	
20.5	4.00	
31.0	8.00	
58.0	10.00	
125.0	13.00	
250.0	14.00	limiting
to		
5 volts	14.00	

AMPLIFIER # 2.

Peak output vs r.m.s. input
@ 510 c.p.s.

FIGURE 18

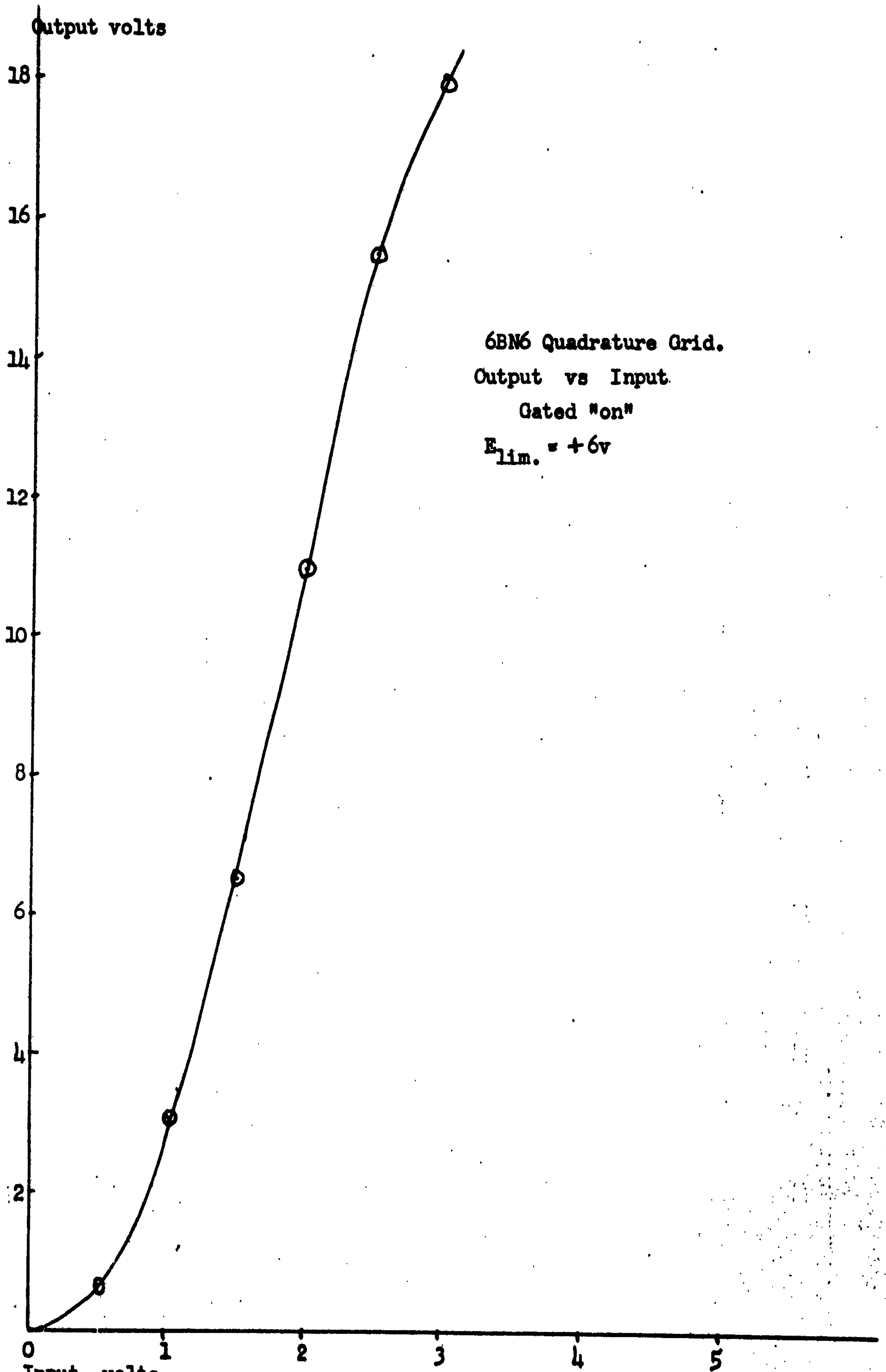

Output volts
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
Input, volts
6BN6 Quadrature Grid.
Output vs Input
Gated "on"
$E_{lim.} = +6v$

Figure 19

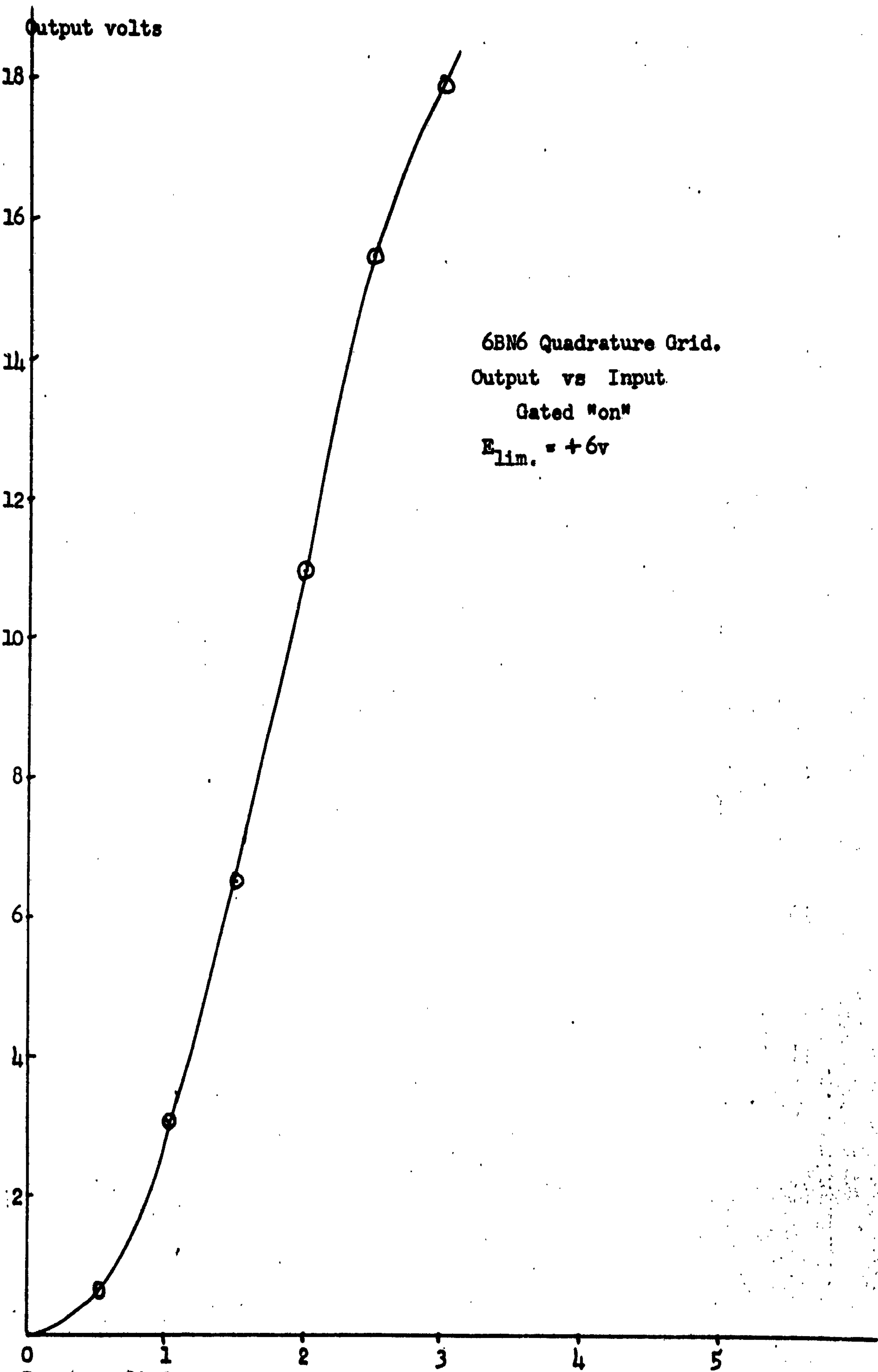

Output volts
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
Input, volts
6BN6 Quadrature Grid.
Output vs Input
Gated "on"
$E_{lim.} = +6v$

Figure 19

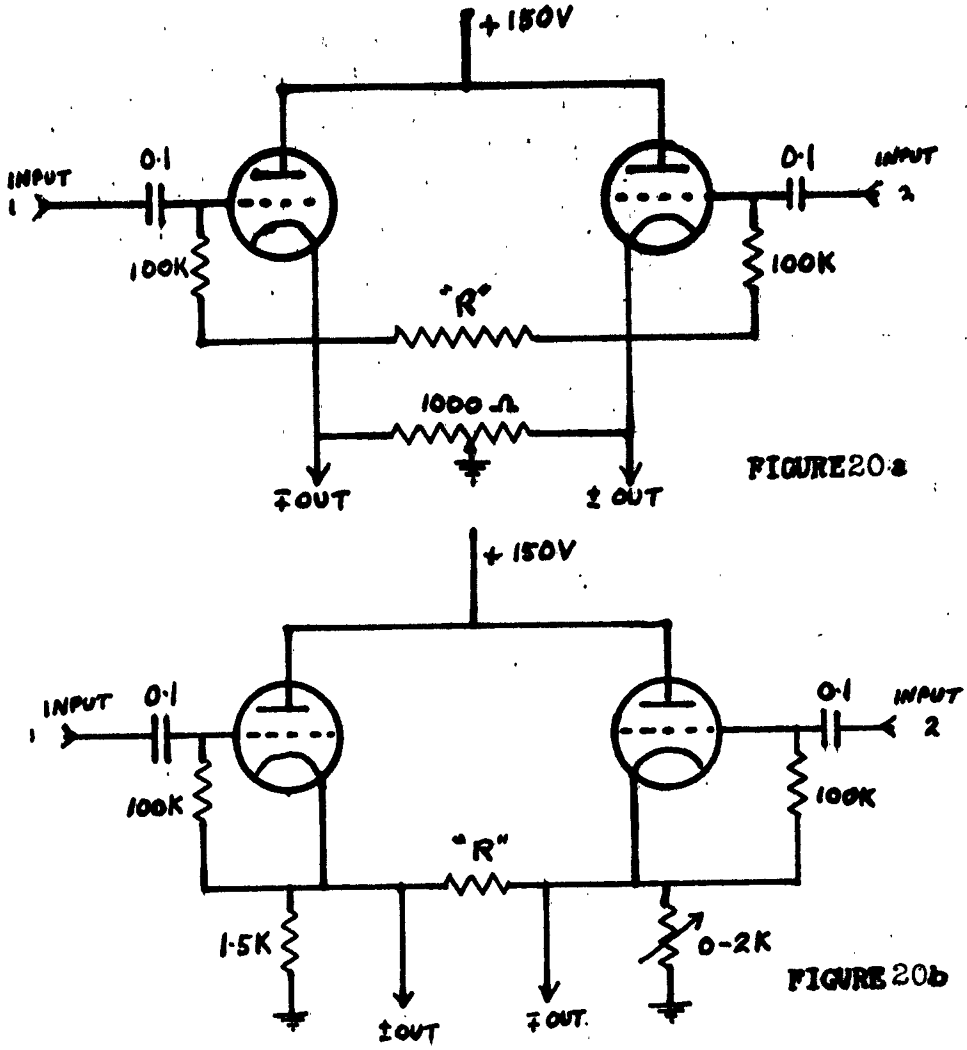
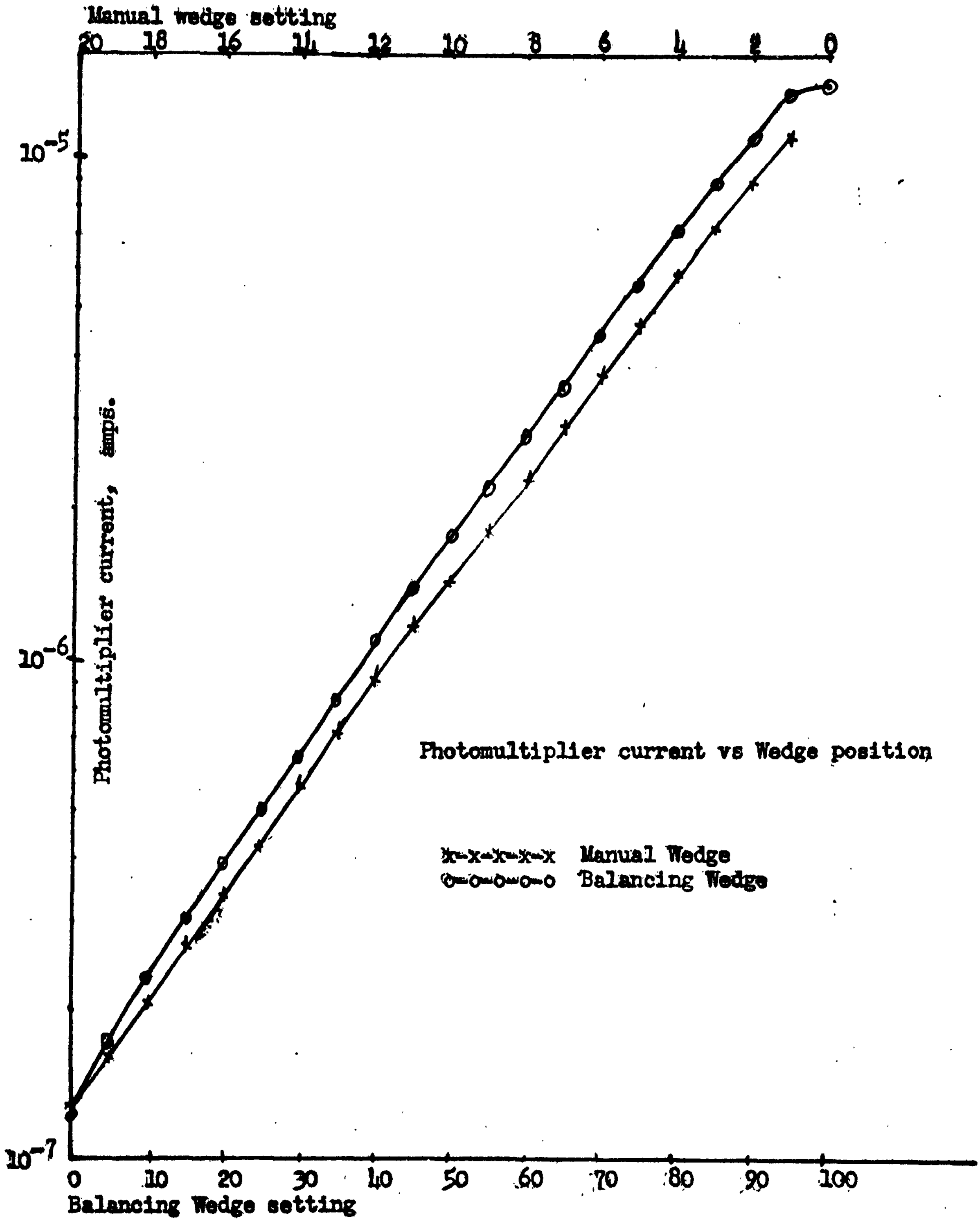
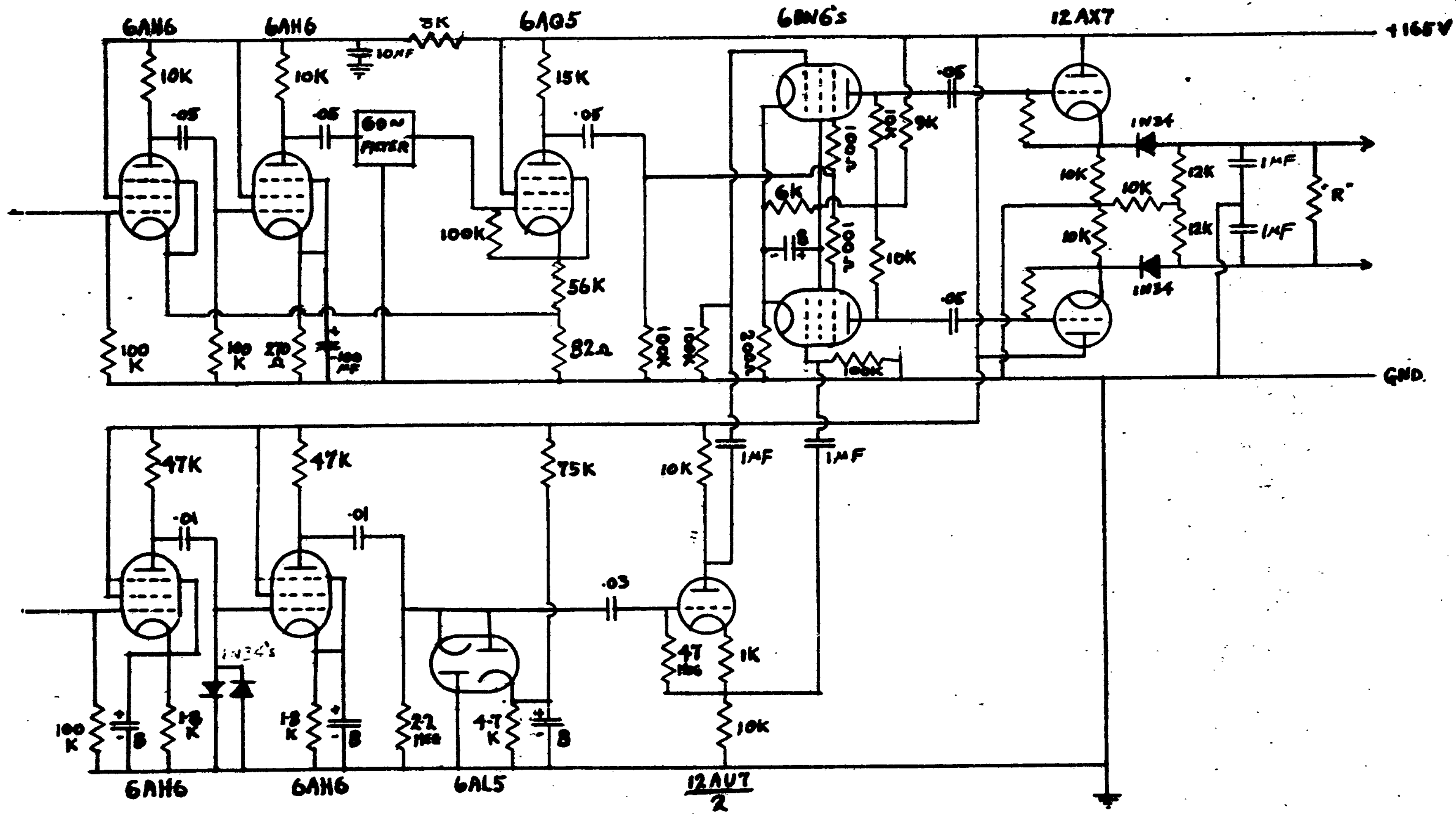

+150V
INPUT 1
0·1
100K
"R"
1000 Ω
0·1
INPUT 2
100K
OUT
OUT
FIGURE 20a
+150V
INPUT 1
0·1
100K
"R"
1·5K
OUT
OUT
0·1
INPUT 2
100K
0-2K
FIGURE 20b

Figure 20



WEDGE CALIBRATION CURVES.

Figure 21



SCHEMATIC CIRCUIT DIAGRAM, AMPLIFIER #3

FIGURE 22

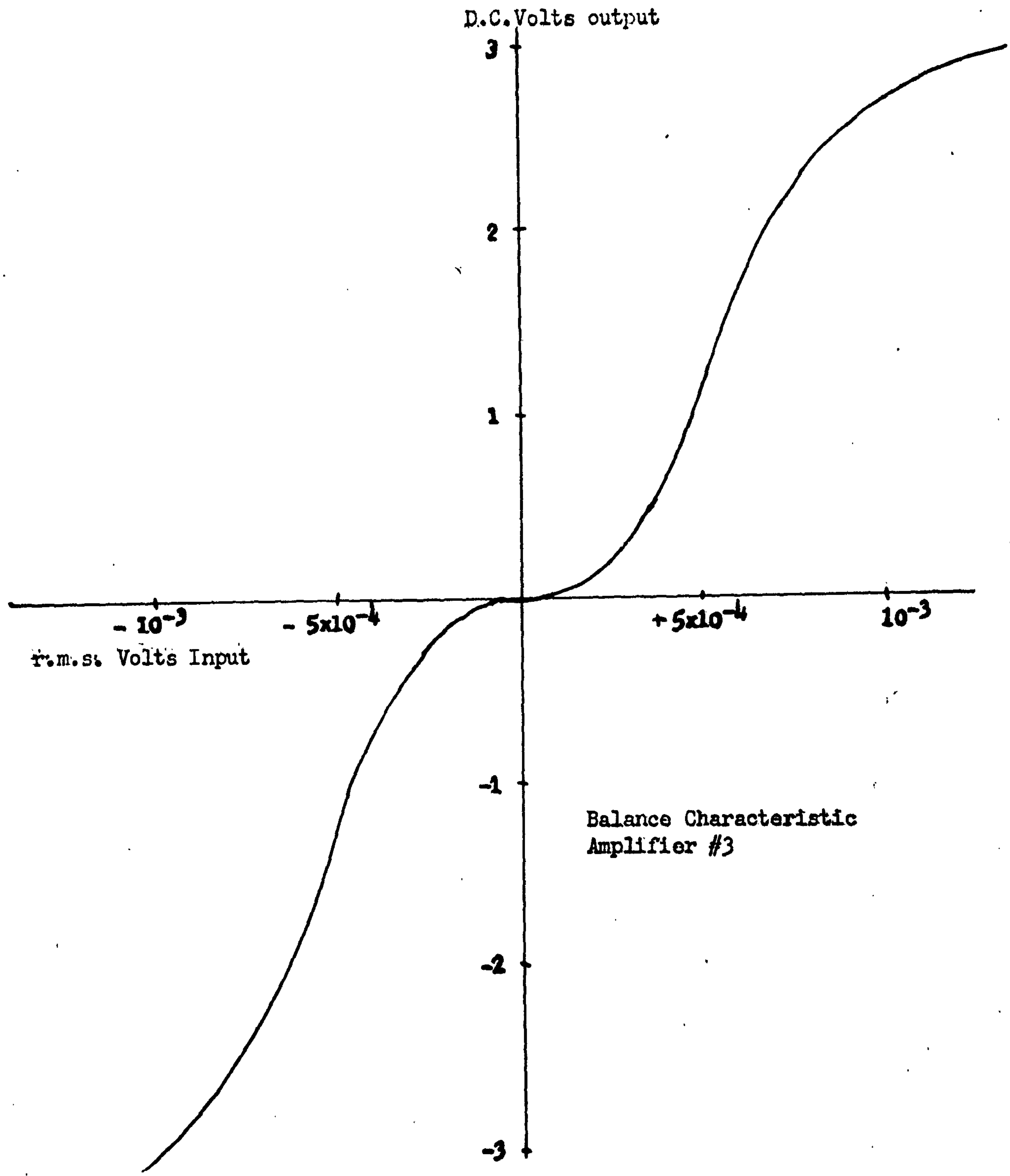
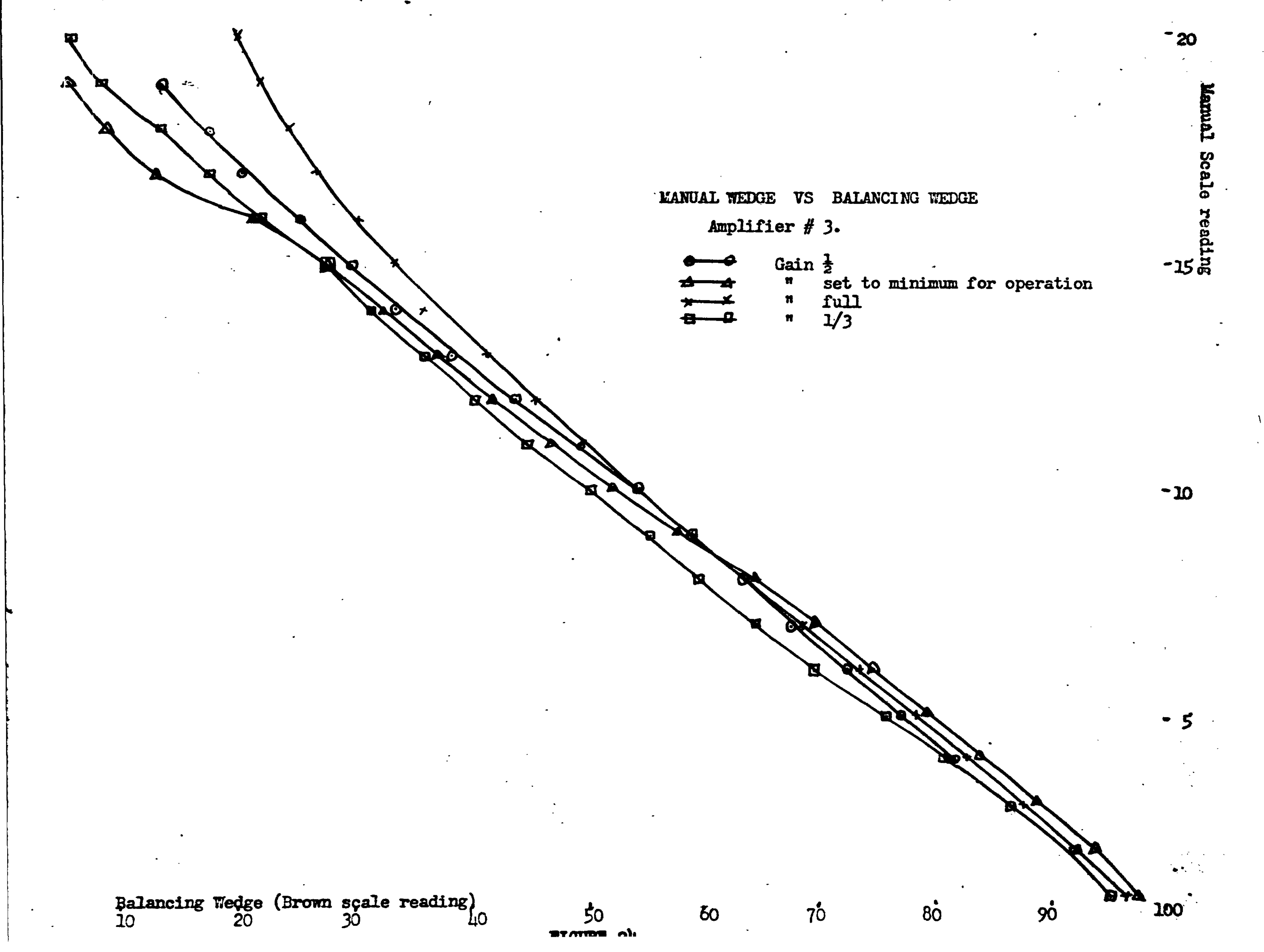

D.C.Volts output
3
2
1
-1
-2
-3
- 10⁻³
- 5x10⁻⁴
+ 5x10⁻⁴
10⁻³
r.m.s. Volts Input
Balance Characteristic
Amplifier #3

Figure 23


MANUAL WEDGE VS BALANCING WEDGE
Amplifier # 3.
Gain ½
" set to minimum for operation
" full
" 1/3
Manual Scale reading
-20
-15
-10
- 5
Balancing Wedge (Brown scale reading)
10
20
30
40
50
60
70
80
90
100

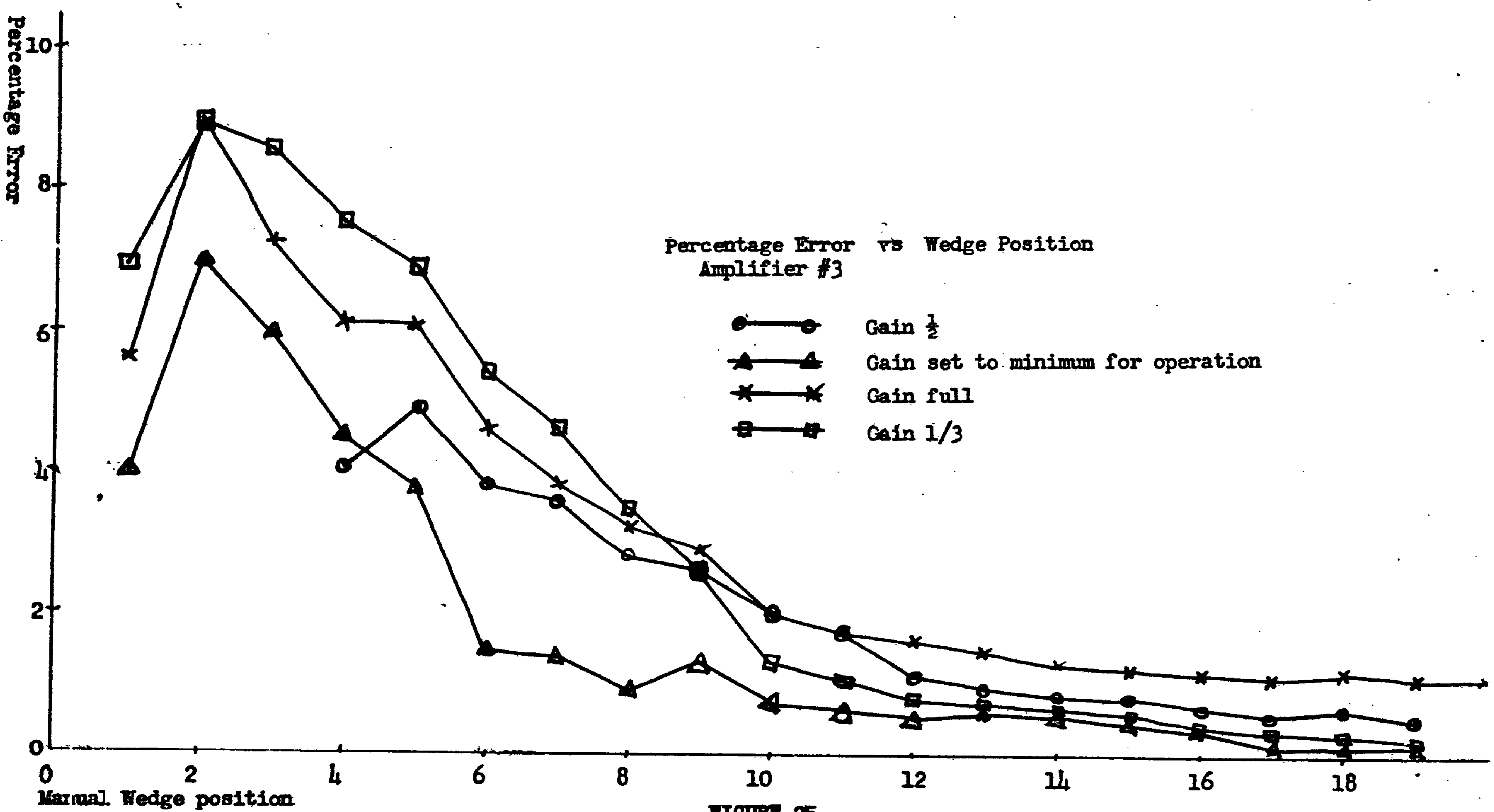
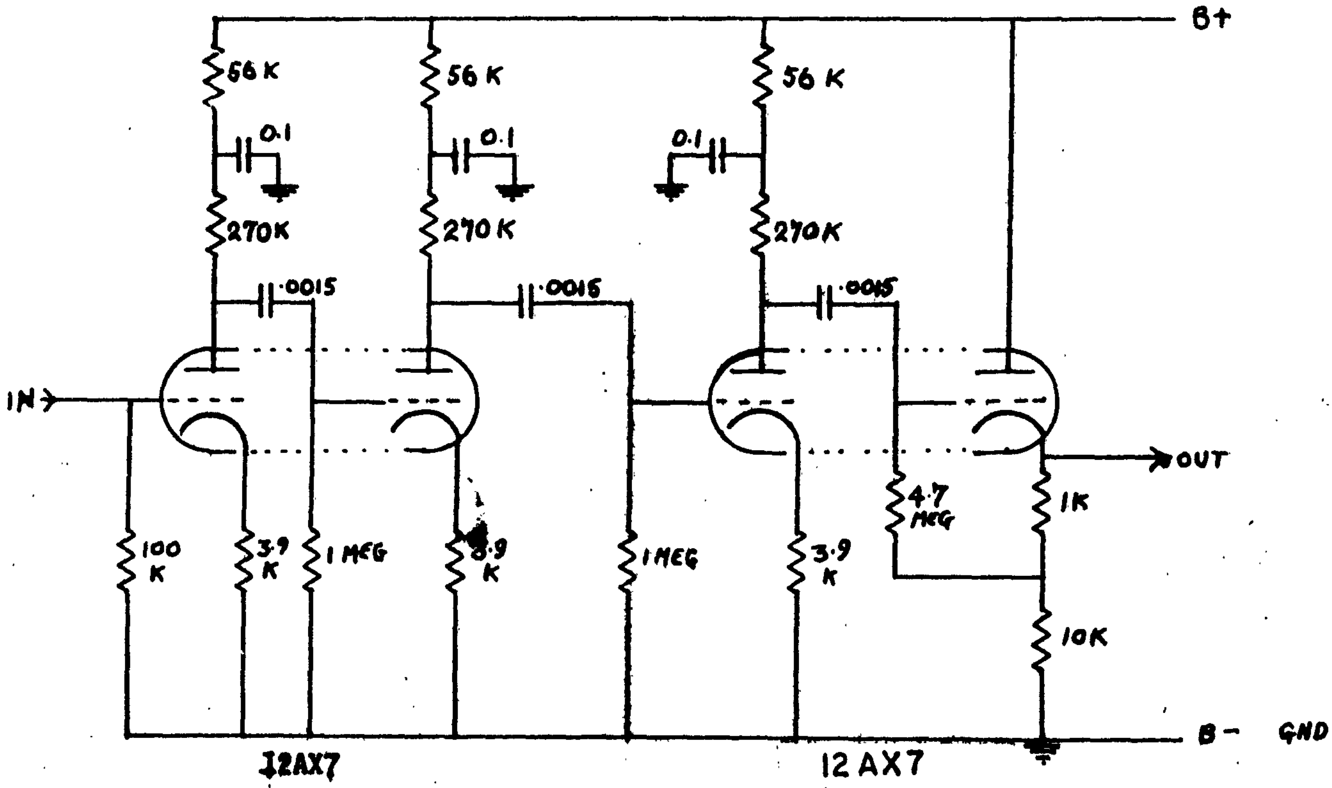
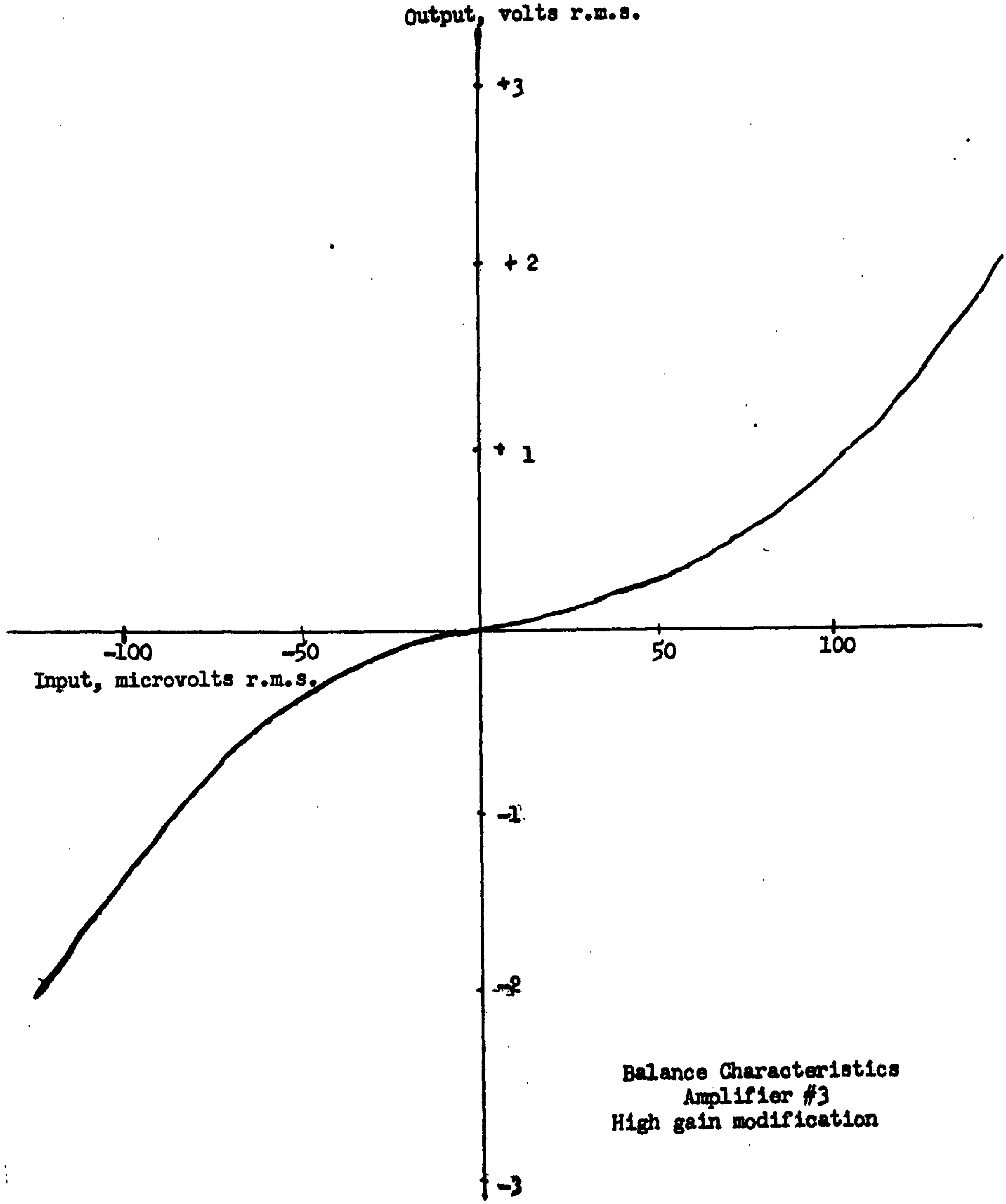

Percentage Error
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
Manual Wedge position
Percentage Error vs Wedge Position
Amplifier #3
Gain ½
Gain set to minimum for operation
Gain full
Gain 1/3

FIGURE 25



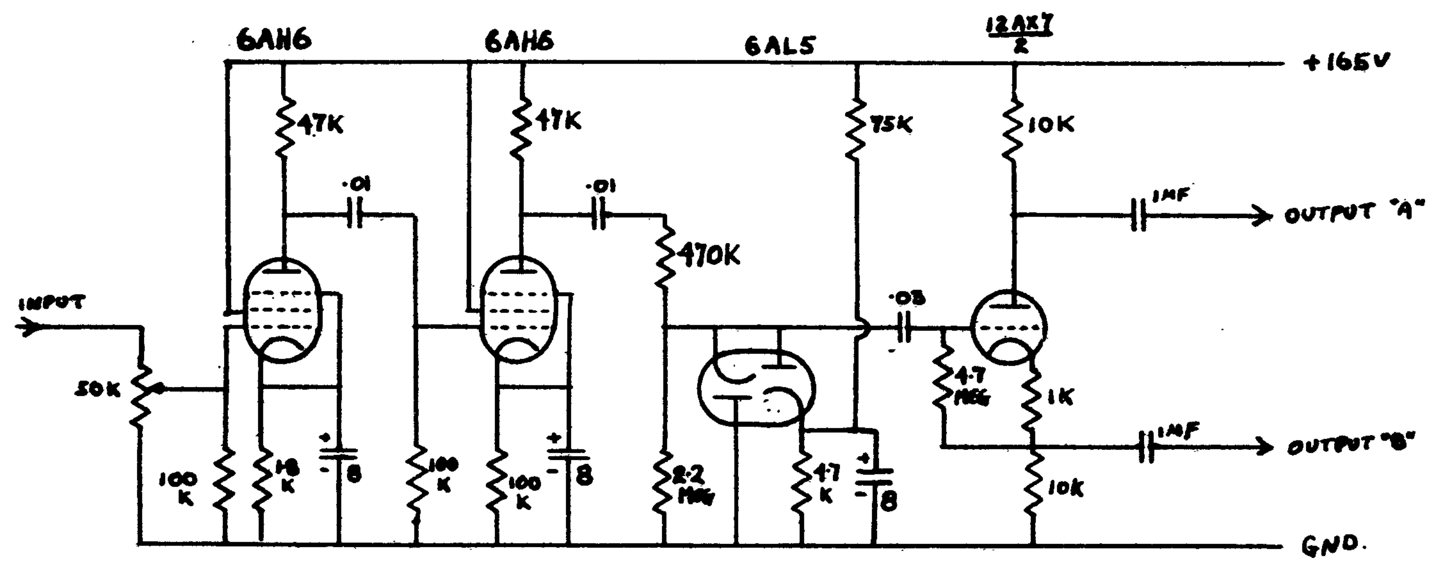
High gain main amplifier
Amplifier #3

Figure 26



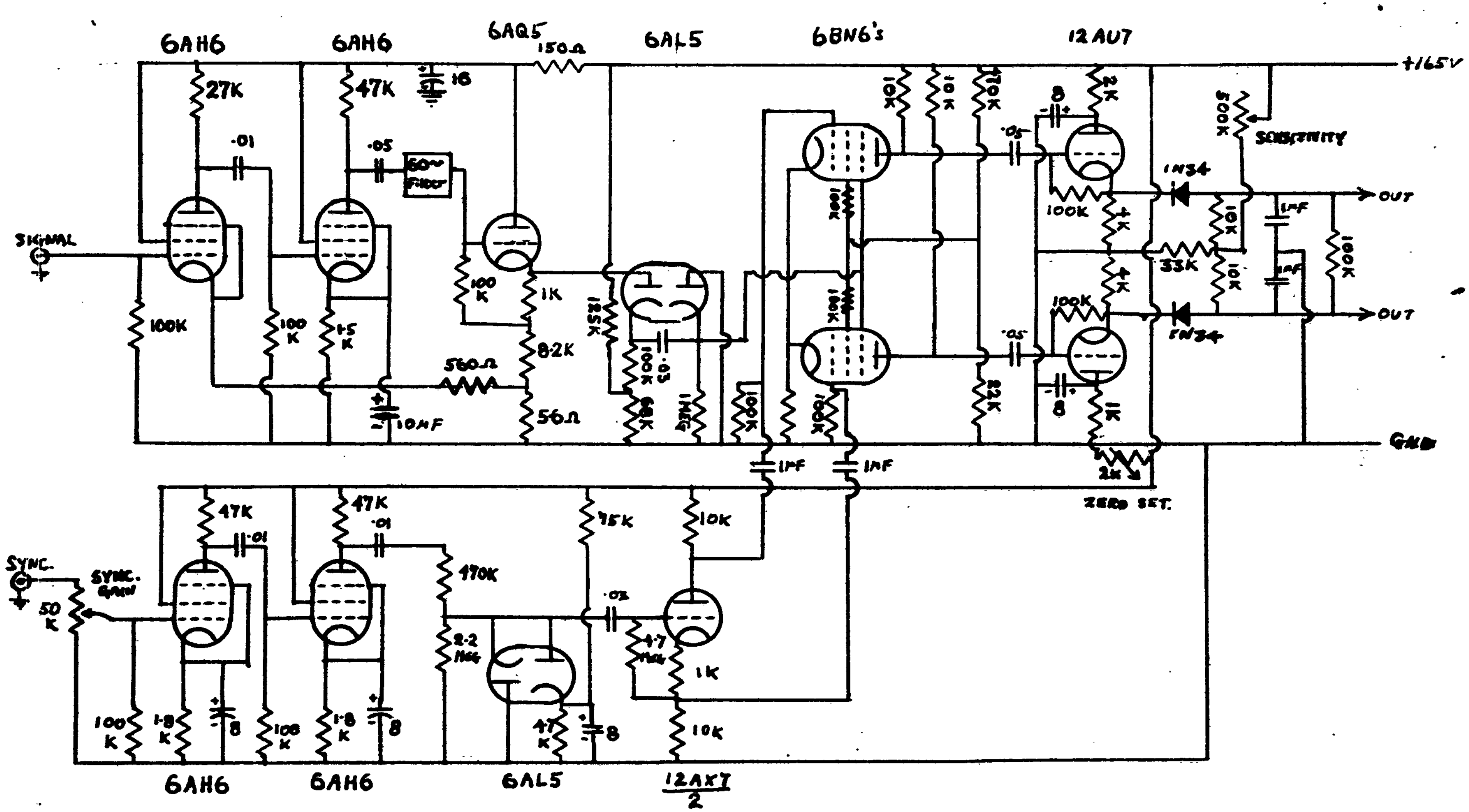
Output, volts r.m.s.
+3
+2
+1
-1
-2
-3
-100
-50
50
100
Input, microvolts r.m.s.
Balance Characteristics
Amplifier #3
High gain modification

Figure 27



Amplifier #3, Modified Synch. Amplifier,

FIGURE 28



Schematic, diagram, Amplifier #3 (modified)

FIGURE 29

Amplifier #4

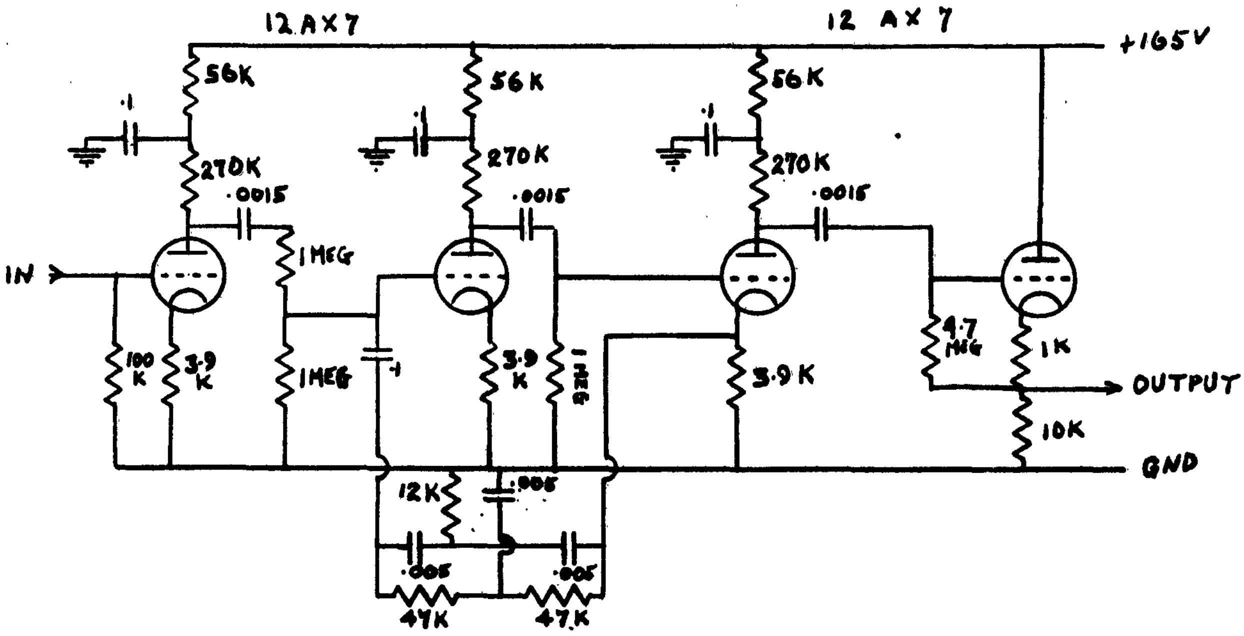


Fig. 30a Twin-tee filter tuned amplifier.

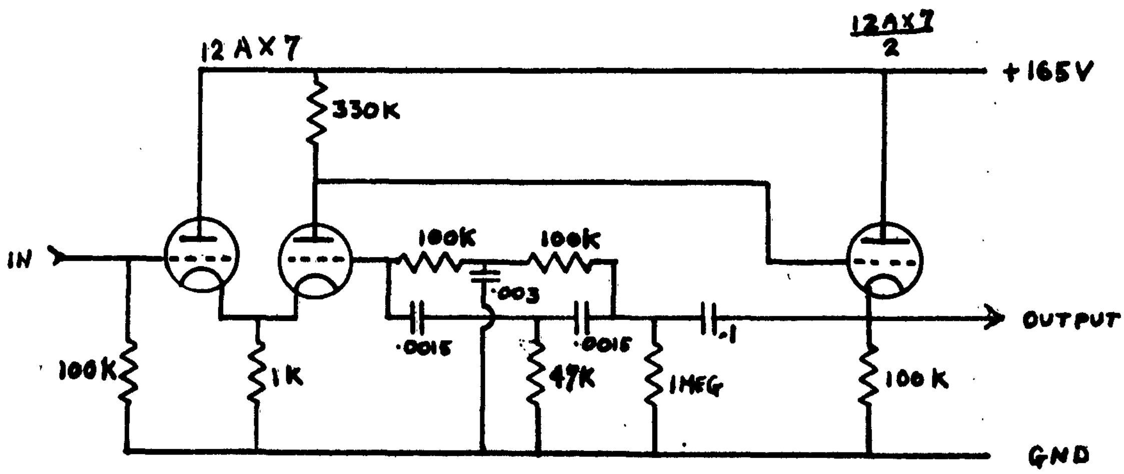
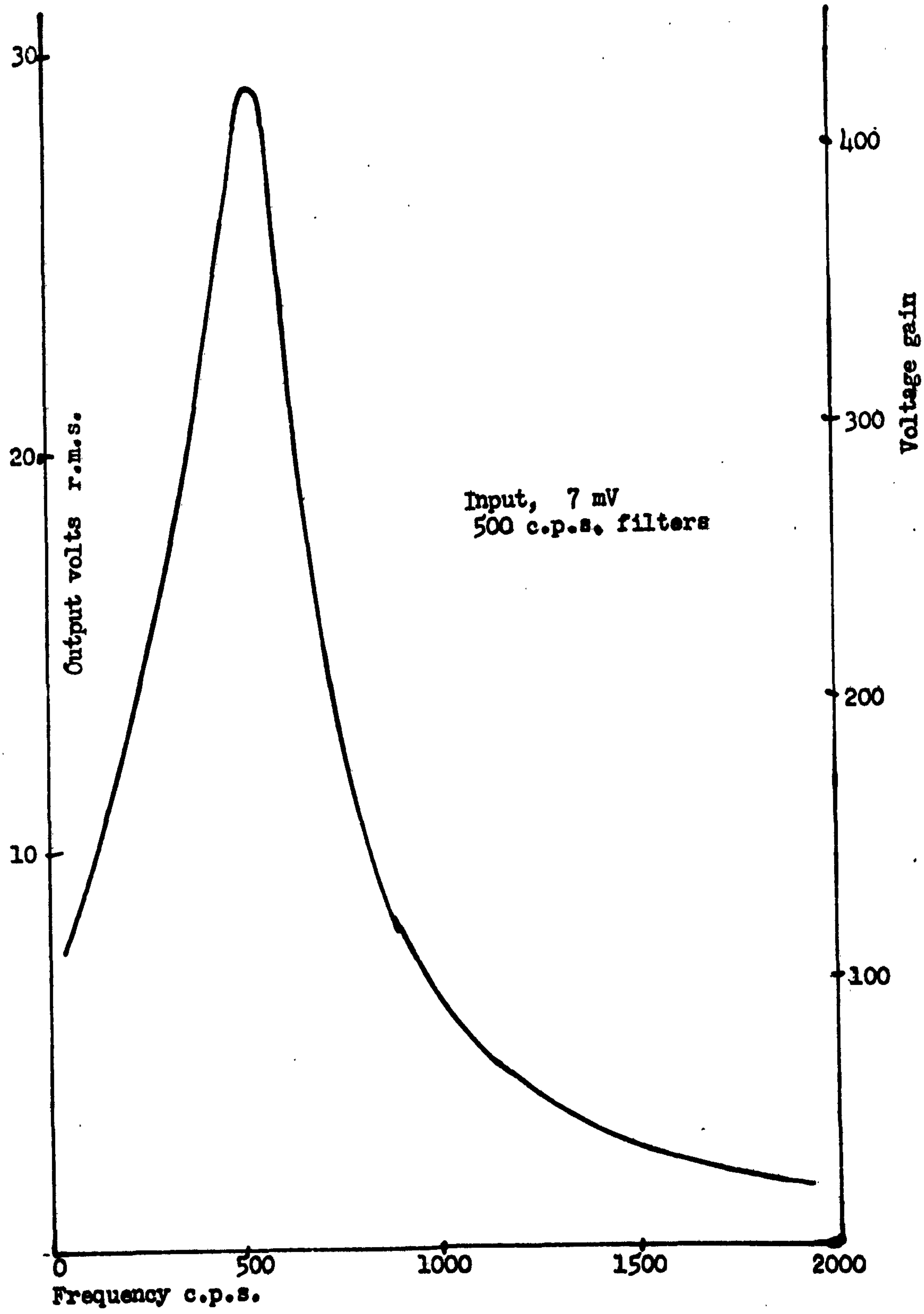


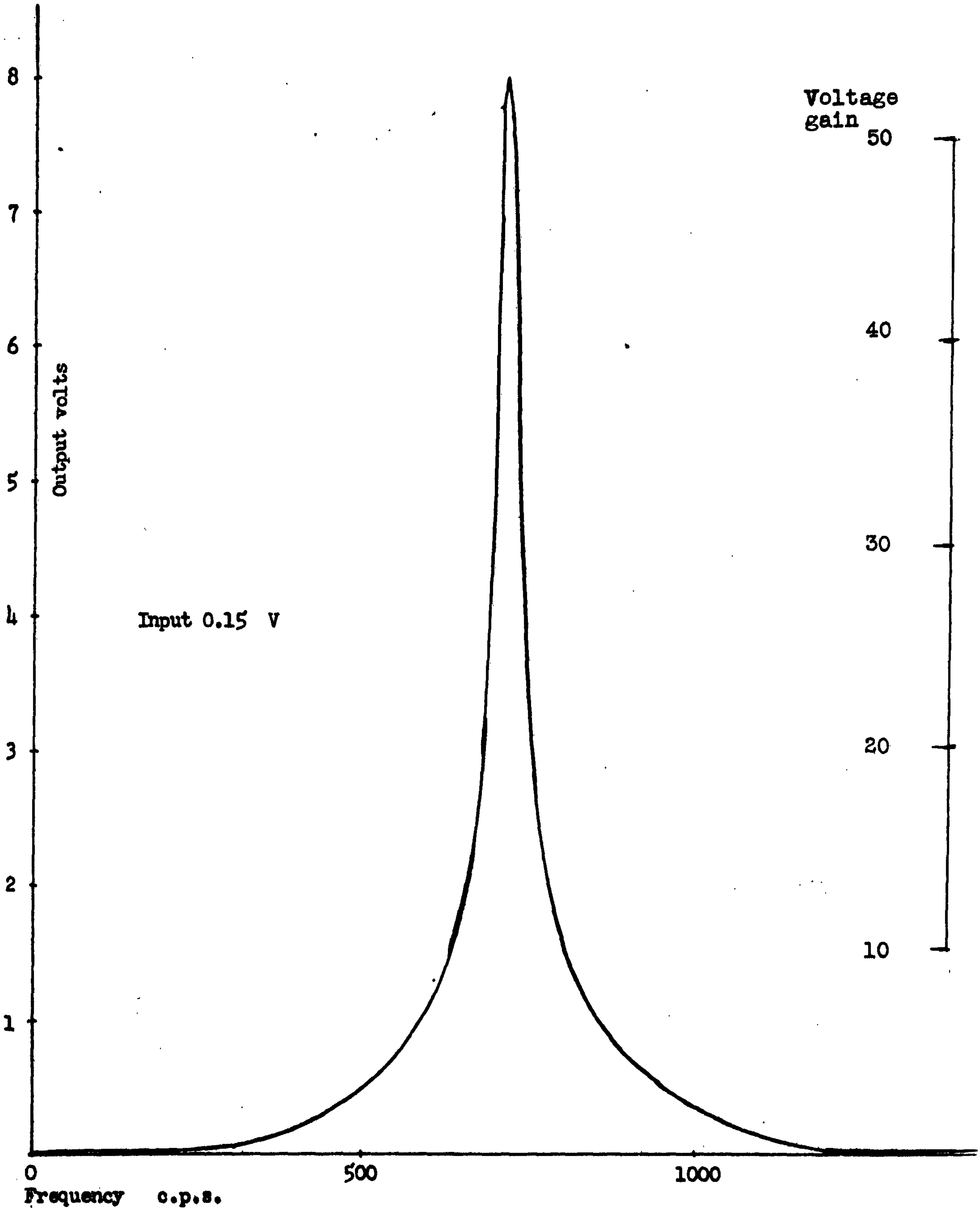
Fig. 30b Cathode fed twin-tee tuned amplifier.

FIGURE 30



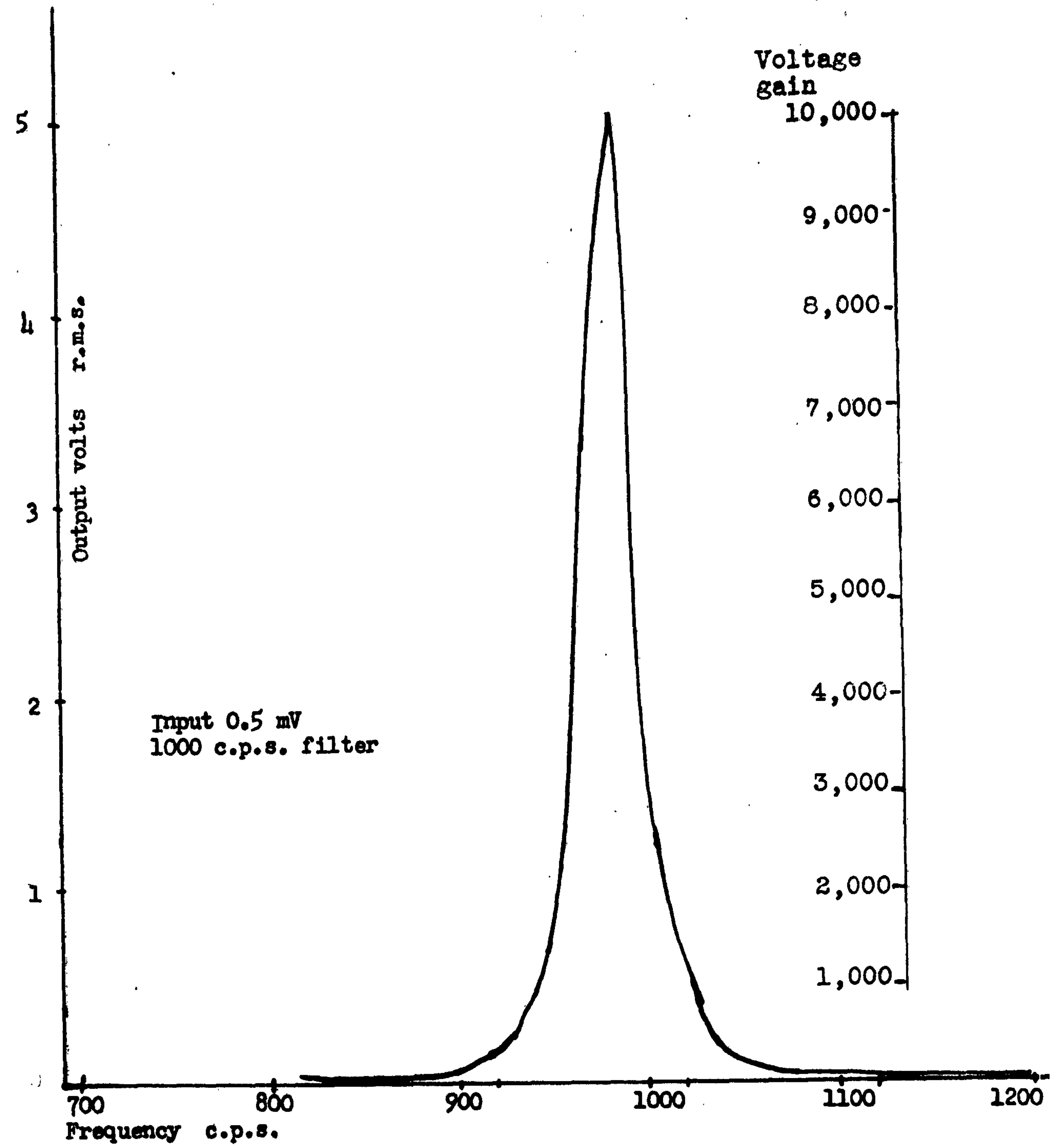
Frequency response & Gain
Tuned amplifier #4 (Circuit 23a)

Figure 31



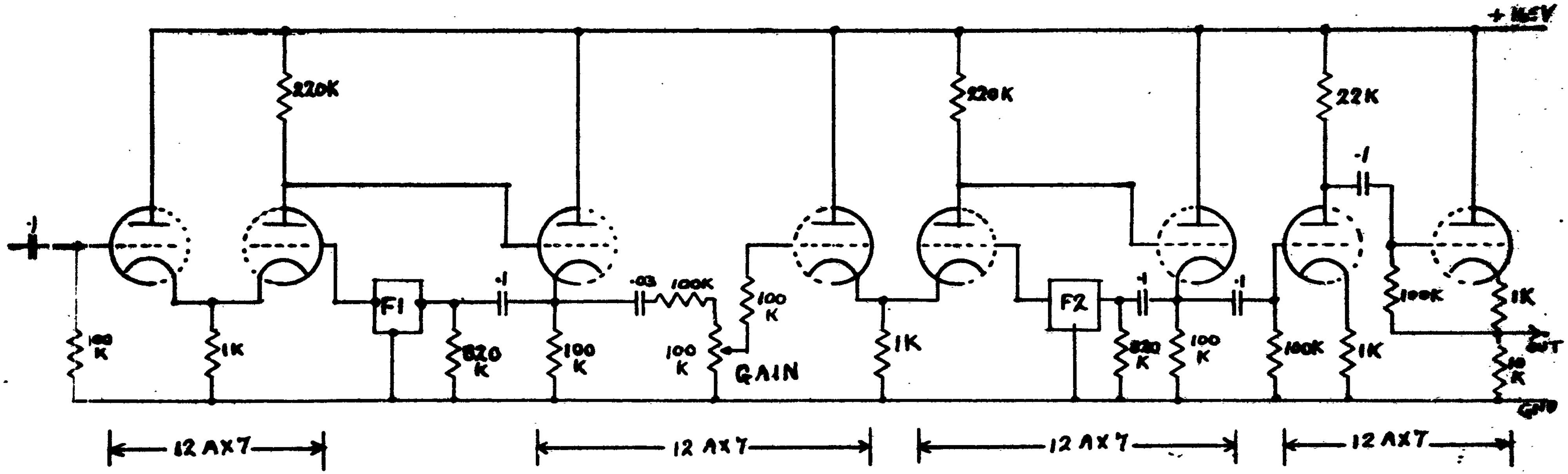
Frequency response & Gain.
Cathode-fed tuned amplifier (circuit 23b)
Amplifier #4

Figure 32



Frequency response & Gain
Two tuned stages in cascade.

Figure 33

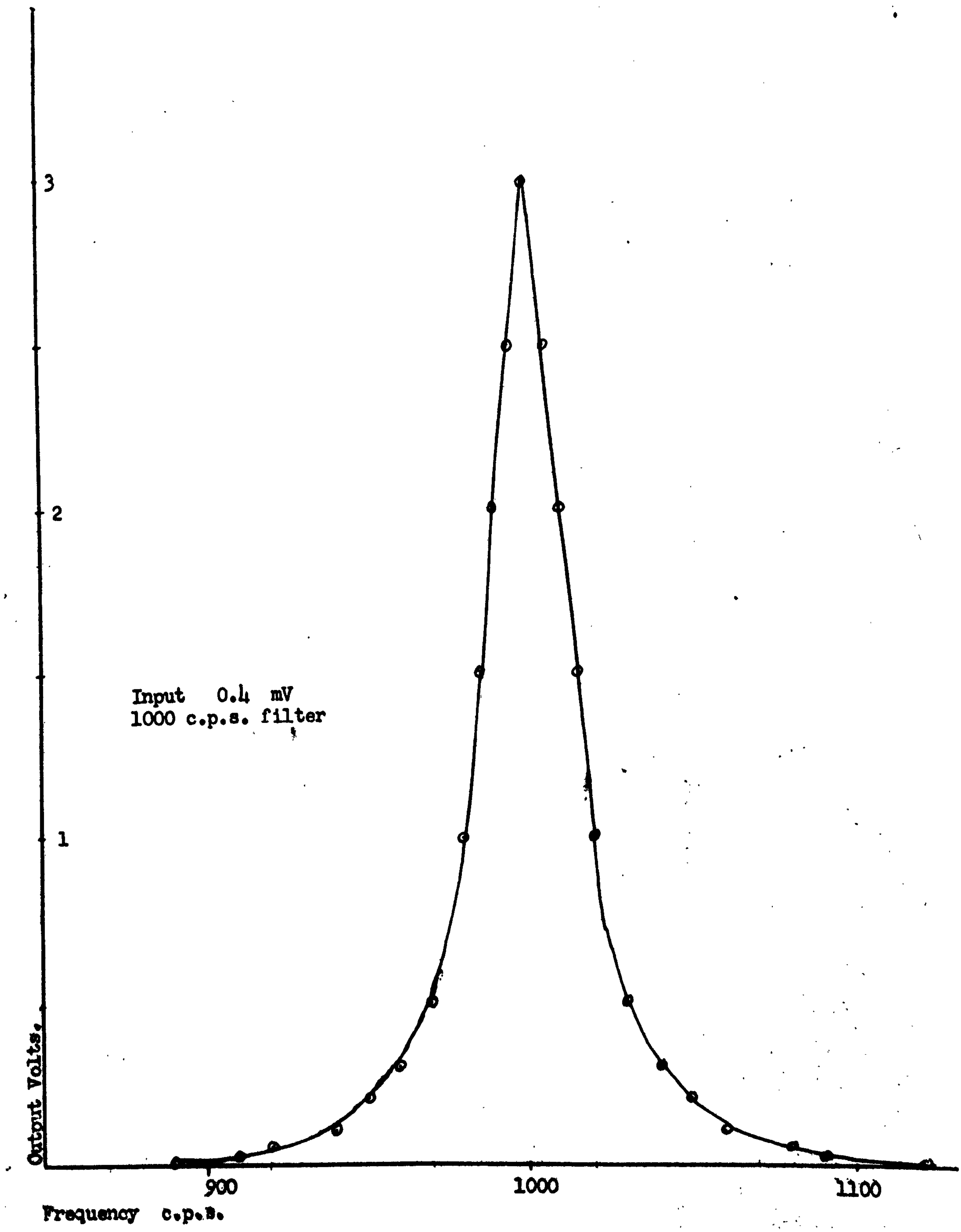


Schematic diagram, experimental tuned amplifier #4

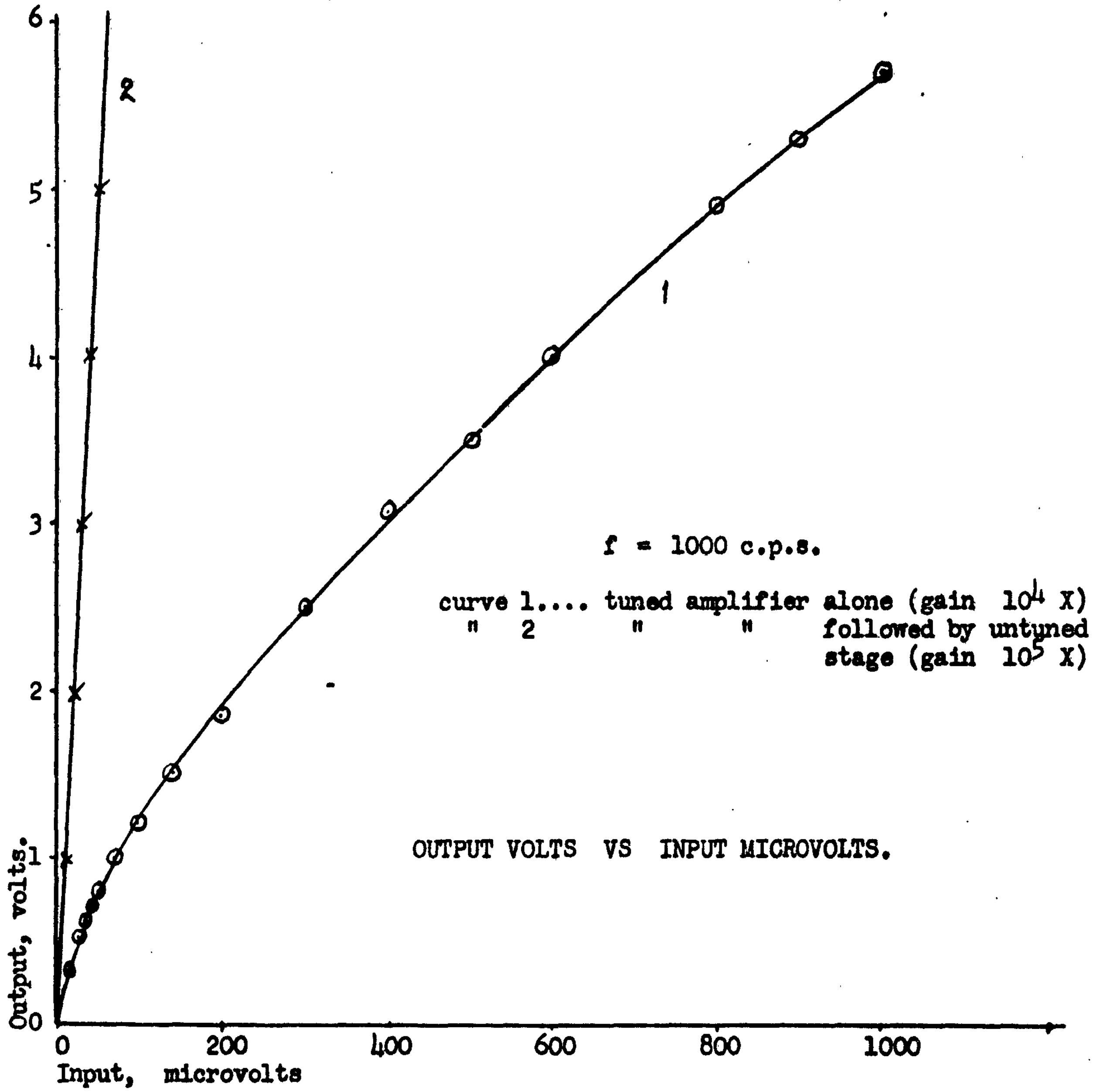
F1 & F2, Twin-Tee filters, adjustable and tunable.

Maximum overall gain 10^5 X

FIGURE 34



Frequency response
Amplifier #4
Figure 35



Linearity, tuned amplifier #4

Figure 36